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Soil genesis on the stable primary divides of the southwestern Iowa loess province

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by

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INTRODUCTION

Loess deposits cover a large portion of the midcontinent United States extending from the Great Plains on the west to the Ohio River Basin on the east and southward to the Gulf of Mexico (Thorp and Smith, 1952). Within this area, loess derived soils have been observed to occur in repitative patterns on the landscape. An examination of these patterns reveals the soils to be in belts parallel or subparallel to major river valleys (Norton, 1933). These belts of soils have been studied in Illinois by Krumbien (1937), Bray (1934, 1935, 1937) and Smith (1942). Based on these studies, similar systems of soils observed in Iowa have been studied by Hutton (1947), Ulrich (1950, 1951) and Ruhe (1968, 1969a, 1969b). Hanna and Bidwell (1955) conducted like investigations on the loessial systems of Kansas. Each of these investigations has made its contribution toward more precisely defining both the loess deposits themselves and the soils formed in the loess. The final result has been an explanation of the soils which has been rather universally applied to loess derived soils.

The presently accepted explanation of the systematic occurrence of soils in loess provinces was first applied by Smith (1942) in Illinois and has become known as the "Effective Age Concept." This concept has been developed for Iowa's loess derived soils by Hutton (1947) and Ulrich (1950,

1951). The original thesis proposed that, at any place along a northwest to southeast traverse in southwestern Iowa, the loess was deposited at a uniform rate at the same time as it was being deposited at any other place along the traverse. On the western end, then, the rate of deposition was great and exceeded pedogenesis. On the eastern end, the rate of deposition was slow and pedogenesis expressed itself on the loess during deposition. The length of time since the cessation of deposition is the same and, consequently, pedogenesis equally expressed itself from west to east during the time since deposition ceased.

With the advent of radiocarbon dating techniques, the genesis of the soils of southwestern Iowa has been re-examined (Ruhe, 1968, 1969a, 1969b). The base of the loess, and consequently the time of initiation of loess deposition, has been radiocarbon dated from 24,750 years before present (hereafter abbreviated Y. B. P.) on the western end of the southwestern Iowa loess province to 16,750 Y. B. P. on the eastern end of the traverse. The age of the geologically stable summit surfaces has been placed at 14,000 Y. B. P. (Ruhe and Scholtes, 1955, 1956). On the western end, 10,750 years was required to deposit the loess and only 2,750 years was required on the eastern end. Loess thickness changes systematically from 1200 inches to 90 inches (Ruhe, 1969b) from west to east. Recent dating on loess dark bands as de-

scribed by Daniels et al. (1960) has further aided in calculation cf non-uniform depositional rates at any location (Ruhe, 1969b). The conclusion that, in southwestern Iowa, loess deposition was neither uniform in rate nor constant in time presupposes the credulity of the effective age concept.

In light of these findings, the loess system of southwestern Iowa was re-examined in this study. The objectives were to evaluate the effective age concept within a time framework as established by radiocarbon dating and to arrive at a series of quantifying measurements which would result in a model system demonstrating the systematic universality of loess derived soils. The effects of moisture were to be introduced as a determining factor as mentioned by Hutton (1947) and emphasized by Ruhe (1969a, 1969b).

HISTORICAL BACKGROUND

The very systematic variation in the soils in southwestern Iowa has been studied with constant revision of ideas as the product. Part of the revision has resulted from geologic advancement and part from changes in the tools employed in pedologic investigations. The geologic and pedologic background are presented below.

Surficial Deposits in Southwestern Iowa

All the unconsolidated surficial materials of southwestern Iowa are identified with the Pleistocene Age and the associated glacial activity. When pedology is introduced, the activities and processes of the Holocene Age are included with the Pleistocene Age to encompass the Quaternary Epoch. The base of the Pleistocene Age is somewhat vague when definition by time is attempted. It appears to extend back for at least 1,000,000 years (Leet and Judson, 1961) and perhaps 2,000,000 years (Holmes, 1965). Within the current framework of knowledge, definition by stratigraphically identifiable materials is more precise.

Prior to 1821, extensive glaciation, reaching far beyond the borders of glacial activity at that time, was not generally accepted by the geologic profession. At that time, J. Venetz, a Swiss engineer, presented to the Helvetic Society the idea that glaciation had been extensive in Europe. These

ideas were met with complete skepticism. Jean de Charpentier allied with Venetz in 1834 and, in 1836, persuaded J. L. R. Agassiz, a zoologist, to travel with him in Europe and examine present glacial activity and evidence of similar past glacial activity. So impressed was Agassiz that the following year he addressed the Helevetic Society on the subject of continental glaciation. His views were put forth so convincingly that many former skeptics became supporters. Agassiz carried his views to England in 1840 and in 1846 to North America when he joined the staff at Harvard University.

One of the earliest workers in North American glacial geology was T. C. Chamberlin who, in 1883, established the existence of at least two glaciations during the events of the Pleistocene Age in North America. At that time no nomenclature was assigned to these glacial stages, but as investigations preceded, more materials were identified and named.

The oldest Pleistocene deposits have been related to the Nebraskan glacial stage (Shimek, 1909). The surface of this drift was exposed to weathering during the Aftonian interglacial period (Chamberlin, 1895) and the soil which was formed was subsequently buried by Kansan drift (Leverett, 1896). The Yarmouth interglacial (Leverett, 1898) provided time for the development of soil in the Kansan drift and separates this drift from the overlying Illinoian drift (Chamberlin,

1895). The gray, severly weathered and tenacious clay on the Kansan surface could have formed over an extended interglacial period (Kay, 1916a). This material has been referred to in Pleistocene literature as "gumbotil" (Kay, 1916b). Kay's gumbotil has been revised to indicate the Yarmouth-Sangamon paleosol on the Kansan surface where it was exposed to weathering through Yarmouth, Illinoian and Sangamon times. In other words, no deposition occurred on this surface during Illinoian glaciation. The Sangamon surface (Leverett, 1898) occurs on the Illinoian deposits. The youngest, and hence the uppermost deposits are Wisconsinan in age (Chamberlin,1895). At this time, the basic Pleistocene section had been established for North America. Since then, innovation and improvement in stratigraphic techniques has permitted refinement of this basic section with only modification of it as improvement of procedures of investigation have permitted. Five glacial and four interglacial units were recognized (Kay and Apfel, 1929). They were the Nebraskan, Kansan, Illinoian, Iowan and Wisconsinan glaciations and the Aftonian, Yarmouth, Sangamon and Peorian interglacial periods. It was further recognized that both the Nebraskan and Kansan glaciations had covered all of Iowa. These two glacial units and the intervening Aftonian and Yarmouth periods have remained essentially unchanged in terminology and stratigraphic position.

The Peorian interglacial period was deleted as to its position in the Pleistocene by Leighton (1933) who gave an intraglacial rather than interglacial position to it. At that same time (Kay and Leighton, 1933) it was proposed that the Iowan, Peorian and Wisconsin units be considered as part of an Eldoran Epoch. This proposal was short lived. An examination of the Wisconsin stage brought out four substages; the Iowan, Tazewell, Cary and Mankato (Leighton, 1933). This was contrary to the idea of Kay and Apfel (1929) that the Iowan was a separate glacial stage between the Illinoian and Wisconsinan. The discussion of placement of the Iowan between a late substage of Illinoian (Leverett, 1939) or early Wisconsin (Leverett, 1942) was resolved in favor of Early Wisconsin. Leighton and Willman (1950) placed the Iowan as the second oldest substage of the Wisconsin substage. Leighton (1966) objected to this position for the Iowan. The problem of the Iowan was finally resolved by Ruhe et al. (1968) who, rather than place the Iowan stratigraphically, completely removed it from the Pleistocene section in Iowa. This was done on the basis of the presence of stone lines, the absence of paleosols on portions of the landscape and radiocarbon dating, among other characteristic features. In place of the Iowan drift, an Iowan Erosion Surface was proposed (Ruhe et al., 1968) and has been generally accepted.

The Loveland unit in the Pleistocene section was first described as a fluvial deposit (Shimek, 1909). Further examination of its morphology lead to an eolian explanation for its depositional mechanism (Kay, 1924). It was first placed in Late Sangamon time by Leighton (1926) but he later concluded that the lower portion of the loess could be older than Late Sangamon at least in eastern Iowa. A Late Sangamon paleosol was associated with the Loveland Loess. Since only a small portion of southeastern Iowa was glaciated during Illinoian time, all the loess below the Sangamon and Late Sangamon paleosols was ascribed to Illinoian time (Ruhe, 1968).

The loess which is superjacent to the Sangamon paleosol was thought to have been deposited continuously from Iowan through Peorian and into early Wisconsin times (Kay and Graham, 1943). The paleosol which Leighton had identified as late Sangamon was redefined as the Farmdale paleosol (Wascher, Humbert and Cady, 1947) to span the time-stratigraphic interval from 22,000 to 28,000 Y. B. P. (Frye, Glass and Willman, 1962). The placement of this weakly developed paleosol in Farmdale time correlated all loess above the Sangamon paleosol with Wisconsin deposition including the Sangamon paleosol (Ruhe, Daniels and Cady, 1967). The surface of this Wisconsin loess, where it passes under the Cary till, has been radiocarbon dated at 14,000 Y. B. P.

(Ruhe and Scholtes, 1956). Radiocarbon dating of the Farmdale increment in Iowa placed its age from 16,500 to 24,500 Y. B. P. (Ruhe, Rubin and Scholtes, 1957). This does not fit into the previously defined time-stratigraphic Farmdale unit. Since by dating, this unit transgressed all of Farmdale and part of Tazewell time units, it was recommended that the Farmdale unit be deleted from the Pleistocene section of Iowa (Fenton, 1966). In its place the name Salt Creek paleosol was suggested since its entire time span could be found in the Salt Creek area of northeastern Iowa (Fenton, 1966). This unit is currently informally referred to as the basal soil of the Wisconsin loess (Ruhe, 1969a). Since it consists only of an A and C horizon, it is interpreted as representative of initial slow rates of loess deposition (Ruhe, 1969b). The compilation of radiocarbon dates from the organic carbon of this basal soil (Ruhe, Rubin and Scholtes, 1957; Ruhe, 1969a), created considerable interest in the undertaking of this study.

Wisconsin Loess Deposition in Southwestern Iowa

Early investigations of the loess of southwestern Iowa produced a theory of aqueous origin of the material (Shimek, 1931). It was proposed that a large lake existed in that part of Iowa that is presently covered by loess. The inequalities in the elevation of the loess deposits was

accounted for by fluctuations in the elevation of the shoreline of the lake. The presence of many fossil mollusk shells, which were classified as either aqueous or semi-aqueous, was interpreted as further evidence for an aqueous mode of origin of the loess. Further observations (Shimek, 1931) produced evidence that the snails which were currently living on the land surface were the same as those buried in the loess. The conclusion was then that the fossil mollusks were in fact terrestrial and furthermore that a temperate environment must have existed at the time of loess deposition. In light of this evidence, an eolian mode of deposition was given to loess. This is widely accepted today as the mechanism of transport and deposition.

Age and environment of loess deposition

Although the mode of loess deposition is fairly well established now, the time period of loess depositional activity has undergone considerable controversy. The name Peorian is credited to Leverett in 1898 (Kay and Graham, 1943) as it was first applied to a weathering interval between Iowan loess and Shelbyville till in Illinois. At the Farm Creek exposure near Peoria, Illinois, this interglacial period is evidenced between Iowan loess and the Shelbyville morainal deposits. Kay and Graham (1943) follow by saying that Shimek proposed that the Iowan loess was not correlative with Iowan drift but

rather with recession of Iowan ice. This proposal was accepted by the geological profession and Peorian loess was placed stratigraphically in the interglacial period which was post-Iowan. This placed all the surficial loess deposits of southwestern Iowa as Peorian loess. With the disproval of the existence of the Iowan drift in Iowa (Ruhe, 1968), the name Peorian has been dropped from use in the Pleistocene section of Iowa and the loess of southwestern Iowa has been referred to simply as Wisconsin loess.

The basal soil of the Wisconsin loess has been sufficiently dated by radiocarbon methods to permit insight into the actual time of loess deposition. Ruhe (1969a, 1969b), in a review of the chronology of loess deposits, concluded that the radiocarbon age of the basal soil (Y) in southwestern Iowa varied with distance (D) from the Missouri River Valley as Y = 26,500 - 55X. From this equation it can be calculated that the mean age of the initiation of loess deposition was 26,500 Y. B. P. near the valley and 16,875 Y. B. P. in southcentral Iowa; the base of the loess becoming progressively younger away from the source area. The time transgressed is about 9625 years. Based on a greater number of radiocarbon dates, Ruhe (1969b) revised this equation to Y = 24,750 - 0.045 D. This was published in obvious error and should have read Y = 24,750 - 45D. By this equation, the age of the basal soil, and consequently the initiation of loess

deposition, progressed from 24,750 Y. B. P. to 16,875 Y. B. P. spanning 7875 years. Since the surface of the loess was dated at 14,000 Y. B. P. (Ruhe and Scholtes, 1956) where it passed under the Cary till of central Iowa, the thick loess in western Iowa was deposited in 10,750 years and the thinner loess of southcentral Iowa in 4875 years.

Within the thick loess of western Iowa occur dark bands interpreted as periods of slow deposition or non-deposition which allowed an accumulation of organic carbon. Several of these dark bands have been radiocarbon dated to permit calculation of approximate rates of deposition (Ruhe, 1969b). Between the basal soil and a dark band 3.3 feet above it, a depositional rate of 0.6×10^{-3} feet per year was calculated. Between two dark bands 9.0 and 27.3 feet below the ground surface, the depositional rate was calculated at 6.9×10^{-3} feet per year. From this it was shown that loess deposition in southwestern Iowa began at varying distances from the Missouri River Valley from 24,750 to 16,875 Y. B. P. and at any given location, had a variable rate of accumulation during the time of deposition. The 0.6×10^{-3} feet per year rate was used to demonstrate that the basal soil did represent an initial slow rate of accumulation which permitted build-up of organic carbon in the material as it was deposited.

As recently as 6,000 years ago, a coniferous forest was present in Iowa (Ruhe and Scholtes, 1956; Ruhe, 1969a). The existance of such vegetation indicates a much cooler and more moist climate existed at that time. Presently, coniferous forests occur in northern Minnesota where the average temperatures range from 0° F to 16° F and average summer temperatures range from 60° F to 66° F. In Iowa, the temperature ranges for these periods is from 14° F to 29° F and from 72° F to 76° F respectively. The difference of about 11° F could easily have existed in association with glacial activity. Rainfall is similar between these two areas, 22 to 32 inches annually in Minnesota and 26 to 36 inches annually in Iowa (Ruhe, 1969a). However rainfall distribution is more seasonally uniform and potential evapotransporation less in the native spruce forest areas of northern Minnesota than in Iowa. Consequently, coniferous vegetation is associated with a relatively more moist environment (Ruhe, 1969a).

Deposition of the Wisconsin loess of southwestern Iowa began from 24,750 Y. B. P. to 16,875 Y. B. P., depending upon proximity to the Missouri River Valley, and accumulated at varying rates at any one location within the loess province. The early views of a temperate climate during loess deposition (Shimek, 1931) appear to be valid and further, the climate was relatively more moist during that period.

Distributional patterns of Wisconsin loess

One of the earliest classifications of the loess of Iowa was made on the basis of color and thickness (Brown, 1936). The Wisconsin loess occurred in western Iowa and extended from the northern state line to the southern state line and eastward two or three tiers of counties. The Mississippi loess occurred in the eastern two tiers of counties in the state. It was reported to have an intermediate thickness of about 25 feet. Located between the Missouri loess on the west and the Mississippi loess on the east and including the first two or three tiers of counties north of the Missouri state line, was the Southern Iowa loess. It was the shallow, gray colored loess. The Missouri loess of southwestern Iowa was observed to have different topographic characteristics at different locations (Kay and Graham, 1943). The area of loess depositional topography included the thickest loess deposits of western Iowa near the Missouri River Valley. The area was characterized by great local relief resulting from the loess accumulations which greatly accentuated and obliterated the underlying Kansan topography. The next area to the eastward was the loess mantled erosional topography where the underlying Kansan surface was modified but not obliterated by the loess. The loess was restricted in occurrence to the summits and upper slope positions on the

landscape thereby increasing the amount of local relief. Still further to the eastward the loess was deposited only on broad ridgetops and divides or was eroded from sideslopes contemporaneously with deposition and had very little effect on relief.

One of the first efforts at quantification of the previously rhetorically observed loess thickness distributional patterns was made by Krumbein (1937). The work was done in Illinois southeastward away from the Mississippi River. An examination of loess thickness in road cuts revealed that, from a distance of two to nine miles away from the river, the loess thinned as $Y = e^{-0.17}$ where Y = thickness and X = distance in miles. At distances of less than two miles, the equation could underestimate loess thickness. This was associated with sand piling off the flood plain of the river in conjunction with loess deposition. Observations which were essentially restricted to road cuts were unable to detect loess thinning at distances greater than 13 miles away from the river. Krumbien's work was later re-evaluated with the addition of hand augered thickness measurements (Smith, 1942). This data was fitted to an equation of the form Y = A - B log X where Y = thickness, A and B are constants and X equals the distance from the river.

Applying the techniques of Smith to southwestern Iowa, two traverses were established for study which were felt to

follow distributional patterns (Hutton, 1947). Traverse 1 began ten miles inboard of the loess bluffs along the Missouri River and had a distributional thickness equation of Y = 1250.5 - 528.5 log X. Traverse 2 began at the bluffs. From 0.1 to 6.88 miles from the base of the first loess bluff, thickness was described as Y = 1100 - 325.8 log X. The remainder of the traverse, up to 86.7 miles from the bluffs, was described as Y = 810 - 343.6 log X. The equation for the first part of traverse 2 did not fit the data well. The difficulties encountered in quantifying this area depositionally were attributed to extremely active erosion in the bluff area coupled with the inability to bore deeply enough with hand equipment for accurate thickness measurements. Two additional traverses were studied in southwestern Iowa and produced equations of the same general form to describe loess thickness patterns (Ulrich, 1950).

Ruhe (1969a) utilized the equations developed by Hutton (1948) to describe the entire southwestern Iowa loess province, but described the loess thickness along the Rock Island Railroad from Bentley to Adair, Iowa, with the equation $Y = 1/(9.51 \times 10^{-4} + 7.99 \times 10^{-5} X)$ where Y is loess thickness and X is distance. This equation is a marked departure from previous equations but the 50 railroad cuts studied were not aligned with loess distributional patterns. This current study was laid out to follow more precisely the loess

depcsitional patterns of southwestern Iowa as defined by loess thickness patterns.

Weathering zones in the loess

At the time of loess deposition, it may be assumed from its mode of transport, the material was in a chemically oxidized form and further, that it contained calcium and magnesium carbonate minerals. The loess has not, however, remained completely unaltered. Aside from the pedogenic affects apparent on the surface, certain weathering zones are observed in the loess.

Geologically speaking, the soil solum represents the uppermost portion of a sequence of chemically and physically distinct weathering zones (Ruhe, 1969a). These weathering zones are defined on the basis of the presence or absence of calcium and magnesium carbonates and the form and distribution of iron within the matrix. The carbonates are determined simply by effervesence with HCl and the iron form and distribution primarily by color. Six weathering zones have been described in loess although all zones may not be present at any one location (Ruhe, 1969a).

Generally, on flat or slightly rounded summits and in thick loess deposits, the oxidized and leached zone immediately underlies the soil solum. It is characterized by the absence of carbonate materials and a yellowish brown matrix colcrs. The implication is that the iron is in an oxidized

form and uniformly distributed throughout the matrix. The free iron content, as determined by sodium hydrosulfite extraction, has been determined between 1.5 and 3.5 percent (Daniels et al., 1961). The oxidized and unleached zone has similar matrix colors and iron content but effervesence with HCl indicates the presence of carbonate minerals. Secondary calcium carbonate concretions, referred to as "loess kindchen" commonly occur in the unleached loess along with fossil gastropod shells as previously noted (Shimek, 1931). Deoxidized and leached zones lack carbonates. The matrix color is light gray in which vertically oriented iron oxides in the form of tubules or pipestems occur. The free iron oxide content of the matrix is from 0.3 to 0.6 percent while that of the pipestems commonly ranges from 9 to 26 percent (Daniels et al., 1961). The deoxidized unleached zone is similar in morphology to the deoxidized leached zone and carbonate minerals are present. The unoxidized leached zone is dark gray, blue, bluish green or green colored and is devoid of carbonate minerals. The iron is uniformly distributed throughout the matrix and exists in the reduced state. The unoxidized and unleached zone is similar in morphology and contains carbonate minerals. Where the unoxidized zone exists in the loess, it invariably occurs immediately superjacent to the Kansan surface and may contain considerable organic carbon or wood fragments which have been used for ra-

diocarbon dating.

It has been suggested that the deoxidized zone is a relict feature (Ruhe and Scholtes, 1956). Its morphology indicates a previous condition of reduction and translocation of iron as a result of prolonged water saturation or gleying. The deoxidized zones conform to the underlying, impermeable surfaces but not to the present surfaces. In southwestern Iowa, a hillslope truncates the deoxidized zone. A radiocarbon sample one foot deep in the alluvial fill at the base of the slope was dated at 6800 Y. B. P. It follows that since this surface truncates the deoxidized zone, it must be older than the surface itself. The deoxidized zone itself transgresses two distinct faunal zone assemblages (Ruhe and Scholtes, 1955). Since the fauna are contemporaneous with loess deposition, the deoxidized zone must be a post-depositional feature and must have formed between 14,000 Y. B. P., the cessation of loess deposition, and 6800 Y. B. P., the age of the surface which truncates it.

Pedologic Background

Loess derived soils occur in a repetitive pattern on the landscape and, since loess has a certain inherent regional uniformity, these patterns exhibit a certain degree of universality. This functional relationship was first described as belts of soils parallel or subparallel to major

river valleys (Norton, 1933). Nearest the source area where the loess is thickest, the first belt soils were characterized by a dark, granular surface, a little discernible zone of clay accumulation and a very high percent base saturation. The second belt soils had dark granular surfaces grading into the subsoil. A barely perceptible zone of clay accumulation existed which lead to indistinct horizonation. A moderate base saturation percentage was associated with this belt of soils. The surface of the soils in the third belt was dark but with a slight grayish cast. These soils exhibited a definite zone of clay accumulation and sharp horizon boundaries. These third belt soils had moderate to low percent base saturation. The soils of the fourth belt had a non-granular, brownish-gray surface grading into a heavy zone on plastic clay accumulation, well developed structure and sharp horizon boundaries. These soils were base unsaturated. In the fifth and final belt, the soils had a friable, gray surface and a gray subsurface. The subsurface had a heavy zone of plastic clay accumulation and sharp horizon boundaries. These soils were highly base unsaturated.

Similar observations were compiled by Simonson in 1943 for Iowa but the work was never published. Simonson constructed a complete soil association map (Appendix A) for the state including the southwestern loess province. The mor-

phology of the soils in each of the five belts reflects the soils described by Norton (1933). The most recent soil association map of Iowa was published in 1965 (Oschwald et al.).

In light of the earlier described series of soils, Krumbein's quantification of loess thickness, and other studies of loess derived soils (Bray, 1934, 1935, 1937), Smith (1942) undertook to assemble and analyze data on the loess derived soils of Illinois to propose an explanation of the reported differences. Hutton (1947, 1948) and Ulrich (1950, 1951) and Ulrich and Riecken (1950) followed Smith's lead and conducted similar studies on the southwestern Iowa loess province.

The effective age concept

Smith's work in Illinois in 1942 was a pioneering study attempting to fit soil characteristics to parent material distribution and derive an explanation for the observed functional relationships. He found that soil development, as reflected in morphology, increased away from the source area with decreasing loess thickness as previously noted (Norton, 1933). Furthermore, both mean particle size and the percent of coarse silt (50 - 30u) decreased with increasing distance away from the source area. Conversely, the amount of fine

silt (20 - 10 u) increased with increasing distance (X) as Y = A + B log X. Also, the percent calcium carbonate equivalent (C) decreased with distance (X) as C = A - B (1/X).

Tc arrive at an explanation and description of the observed differences in the soils of a loess province, Smith (1942) employed the depth of leaching of carbonates. On the basis of palentological interpretations, the existance of arboreal vegetation during loess deposition was postulated. Therefore, the amount of leaching of calcium carbonate under arboreal vegetation was used as a measure of weathering since the cessation of deposition. The depth of leaching times the calcium carbonate equivalent of the layer immediately underlying the leached zone provided a measure of removal. The average value of a large number of samples was found to represent a layer of calcium carbonate particles 17.7 ± 0.5 inches thick removed since the close of loess deposition. This was assigned a relative value of 1.0 time units. The weathering since deposition was equated to leaching losses under prairie vegetation and was found to represent a layer of calcium carbonate particles 11.8 inches thick. The total thickness of calcium carbonate removed during and since loess deposition would be a layer 29.8 ± 3.0 inches thick. The ratio of leaching losses during deposition to the losses since deposition is 1.7 time units. The thickness of the solum was then related to the thickness of the loess as a 30

inch solum in 300 inches of loess, 30/300 or 1/10. The relative effective age of this soil would be 1.0 time units, leaching during deposition, plus one half the time required to deposit the upper 1/10 of the loess or 1.0 + (1.7/10 x 1/2) = 1.1 time units. If both the solum and the loess were 30 inches thick, the effective age would be 1.0 + (1.7 x 1/2) = 1.85 time units. This forms the basis of the widely accepted effective age concept.

A necessary qualifying assumption made in this explanation was that at all places during loess deposition, the rate of accumulation was uniform. Where the loess is thick then, the rate of deposition greatly exceeded the rate of leaching and the soils effectively weathered only since deposition ceased. Where the loess is thin, the rate of weathering exceeded depositional rates and the soil has effectively weathered both during and since deposition. This described the differences morphologically observed and gained wide acceptance.

Following this exceptional pioneering work, Hutton (1948) worked on the loess of southwestern Iowa. Again, uniform rate of deposition was assumed. At all places along Hutton's traverses, time since deposition ceased was assumed the same, T1 time units. Where a 30 inch solum was developed in 600 inches of loess, the solum was deposited in 30/600 or 1/20 of the total time of loess deposition, T2. The effec-

tive age here would equal T1 +T2/20 = 1.0 time units. Where the solum is again 30 inches thick but the loess only 90 inches thick, the solum would represent 30/90 or 1/3 of the time of deposition. The effective age would be T1 + T2/3 = 6.24 time units.

This work was supported (Ulrich and Riecken, 1950) in southwestern Iowa on two similar traverses. In addition to support for Hutton's work, the amount of clay in the horizon of maximum accumulation was found to increase with distance as did volume weight. Total and aeration porosity and permeability decreased with distance away from the source area. In 1948, Ulrich published data to show a functional relationship between several chemical characteristics of soils of southwestern Iowa along the loess distributional pattern.

Travelling southwestward away from the Missouri River in Kansas, Hanna and Bidwell (1955) suggested that the change in the soils was a result of the increasing percent of fine size fractions in the loess parent material with distance. This study was restricted to a traverse only 24 miles long. Assuming that the clay content of the B and C horizons is a sedimentologic feature, percent less than two micron clay was related to distance (D) as the clay content of the B horizon = 22.2368 + 21.3544 log D and the clay content of the C horizon = 14.2893 + 19.1490 log D. The correlation coeffi-

cient of both these equations was 0.97 indicating an excellent fit of the data. Ruhe (1969a) has re-examined this data and seriously questioned its interpretation.

Bray (1934) concluded that two types of secondary minerals were formed and redistributed during weathering processes. The first of these was the occurrence of ferromanganiferous oxides as both soft, blotchy mottles and as hard concretions. The amount of these present increased with degree of development under either acid or alkaline conditions. The second set of secondary minerals to form were the silicate minerals.

Most of the secondary silicate minerals which Bray (1934) examined were less than one micron in diameter and mineralogically fit into the beidellite series. He felt that most of the minerals were formed by weathering before the removal of carbonates. He further felt that the differences in the soils he worked with were because of differences in the formation of clays, breakdown to smaller particles and movement and subsequent accumulation of clays within the profile. A later study (Bray, 1937) revealed that the most mobile clay fraction was less than 0.06 microns diameter. The movement and accumulation of this fine clay was what resulted in the claypan formation of strongly developed soils. Moreover, movement of this clay was a result of dispersion and redistribution within the profile by percolating water.

Beavers et al. (1955) reported that the primary clay mineral present in prairie derived loess soils was montmorillonite and further that this montmorillonite had not been materially altered by the processes of soil development. In contrast to Bray (1934), Beavers interpreted the presence of this mineral throughout the profile, and even in calcareous loess, as an indication of its stability. If this interpretation was correct, then the montmorillonite would have been present in the loess when it was deposited.

The origin of the montmorillonite in the loess has been the subject of much debate. Beavers (1957), who said it was a lithologic property of the loess, attributed its origin as a result of electrostatic attraction between clay particles and larger silt particles. Clay particles have been reported to exist as coatings on coarser particles within the southwestern Iowa loess deposits (Davidson and Handy, 1954) and that this clay was montmorillonite. A study of the soils therein resulted in the idea that the major soil forming processes active were cationic eluviation and the formation and redistribution of clay within the soil profile (Hutton, 1948). Most of the movement was in the less than 0.06 micron size fraction, some movement occurred in the 0.06 to 0.20 micron size fraction and none in the 0.20 to 2.00 micron fraction. The clay was of the

montmorillonite-nontronite-illite type with little kaolinite present. This is in agreement with Bray (1934, 1937).

Ulrich (1949) concurred with Hutton (1948) with respect to clay translocation. He went further and stated that fine clay formed at considerable depth in the subsurface. With time and increasing amount of development, the zone of maximum clay accumulation approaches closer to the soil surface.

In agreement with Beavers et al (1955), Jackson (1959) stated that moderately weathered prairie derived soils were generally high in montmorillonite type clay minerals. A portion of this clay was ascribed to a lithologic origin but a large portion was probably weathered from micaceous minerals. Glen et al. (1960) state that most of the montmorillonite in loess soils is formed from weathering of micaceous minerals. It was shown that this weathering could take place prior to the leaching of carbonates, this in agreement with the earlier work of Ulrich (1949), and in fact, that acidification only served to accelerate the reaction.

Whiteside and Marshall (1944) examined the mineralogy of soils formed in loess. They found that coarse clay sizes were primarily quartz, feldspar and a mixture of kaolinite, illite and montmorillonite type minerals. The medium size clay fraction was mostly montmorillonite, illite and kaolinite type clay minerals. The fine clay fraction, less than 0.1 micron, contained some illite but was mostly

montmorillonite. They concluded that one result of soil formation was the production and redistribution of clay minerals which were less than 0.5 microns in diameter.

Whiteside states conclusively that weathering in the clay size fraction of loess derived soils is restricted to the alteration of micaceous minerals to form partially or completely expanded vermiculite or montmorillonite type clay minerals.

In light of improved field and laboratory tools and methodology and with the advent of radiocarbon dating techniques, the concept of effective age of loess derived soils is subject to serious re-examination. The leaching of carbonates itself is little understood and would be questionable when used as a measure of time. The more accurate placement of the loess in southwestern Iowa stratigraphically and a more complete understanding of its chronology allow calculation of depositional rates. Parent material composition is little understood presently as well as disagreement as to the mineralogy of the loess. The logical conclusion reached is that the reasons for the differences in the soils of southwestern Iowa have yet to be completely and clearly elucidated. It is hoped that this study will progress closer to these reasons.

INVESTIGATIONS

The earliest investigation of the relationship of soil properties to loess distributional patterns was conducted on two linear traverses in central Illinois (Smith, 1942). Traverse 1 was established in a southeastward direction away from the Illinois River and traverse two, south of traverse one, travelled in the same general direction away from the Mississippi River. The direction of these traverses was felt to represent the direction of the prevailing winds during the time of loess deposition. In other words, the direction of loess thinning was felt to represent the direction of deposition.

Hutton (1948), following the model established in Illinois (Smith, 1942), established two linear traverses in southwestern Iowa. These traverses,number 1, 171 miles long, and number 2, 90 miles long, extend eastward from the Missouri River Valley to the Iowa-Missouri state line. The direction was established by the reasoning employed by Smith (1942) as representative of the direction of the prevailing wind during deposition. To avoid confusion, Ulrich (1949), numbered two traverses in southwestern Iowa numbers 3 and 4 since they were nearly parallel to Huttons numbers 1 and 2.

The next quantitative study in southwestern Iowa (Ruhe et al., 1967) was not established as a loess-soils relationship study but rather as an investigation of landscapes,

soils and Pleistocene deposits. The study was conducted along the relocation route of the Chicago, Rock Island, and Pacific Railroad and ran generally in an eastward direction from Bentley to Adair in southwestern Iowa. Since this route does not approximate distributional patterns, the relationships observed between loess thickness, soils and distance from the loess source are not too compatable with other studies. Major contributions were made in this publication with respect to Pleistocene geology which have direct bearing on the interpretation of the soil patterns of the area. The most recent and complete reviews have been presented by Ruhe (1969a, 1969b) and include a critical examination of previous works.

Field Study Area

The loess province of southwestern Iowa was chosen as the location for this present study. As previously noted, the area contains many of the type locations of Pleistocene stratigraphy and has had a great preponderance of pedologic investigation carried out on it. The vast background of material available made this area particularly well suited to further investigation. The basal soil of the Wisconsin loess has been extensively radiocarbon dated (Ruhe, 1969a, 1969b) providing insight into the chronology of loess deposition. Several pedologic investigations (Hutton, 1947; Ulrich, 1950;

Ruhe, 1969a; Huddleston, 1969) provided background information on measureable systematic relationships.

Research site locations

Previous investigations into loess-soil relationships have employed straight line traverses felt to be representative of the vectorial properties of loess deposition. The present investigation was established along a geographically curvilinear traverse. The traverse originates in western Harrison County, Iowa and terminates 173.2 miles to the southeast in southern Wayne County, Iowa (Figure 1). The traverse was established to cross normal to previously mapped loess thickness contours (Oschwald et al., 1965; Ruhe and Scholtes, 1956). The traverse was oriented curvilinearly to achieve a better representation of the loess depositional patterns.

The traverse crosses through five recognized soil association areas (Figure 1). These areas together comprise a continuum demonstrating an increasing degree of soil development as reflected in soil morphology from northwest to southeast. The five soil association areas are (Oschwald et al., 1965):

1. Monona-Ida-Hamburg
2. Marshall
3. Shelby-Sharpsburg-Macksburg
4. Adair-Grundy-Haig
5. Adair-Seymour-Edina

Individual field sites were selected along this traverse

(Figure 1). Since one objective of the study was quantification of the loessial system, the selection of geologically stable landscape positions was essential. Three features were deemed necessary for establishment of landscape stability. The first criterion of selection was that the site occur on a primary, upland divide between major drainageways in southwestern Iowa. Further, a north-south orientation of the axis of the divide was necessary since the major drainage of the loess province is primarily from north to south. Finally, the summits, or divides, should have a uniformly flat surface. This criterion of selection precludes erosional stability as an influencing factor in the measurement of loess thickness. A maximum slope of two percent from the horizontal defined the limits of summit width.

With these criteria in mind, individual field sites were selected along the traverse. The complexity of the loess landscape restricted the actual site selection such that the sites did not coincide exactly with the traverse line. The areas were selected as close as possible to the line while fulfilling the requirements for geologic stability (Table 1, 2 and Figure 1).

Figure 1. Map of southwestern Iowa showing location of the research area The open triangles are radiocarbon sections. The solid lines between associations indicate abrupt boundries. LCS is Luton-Cnawa-Salix, MIH is Monona-Ida Hamburg, M is Marshall, SSM is Shelby-Sharpsburg-Macksburg, AGH is Adair-Grundy-Haig, ASE is Adair-Seymour-Edina, L is Lindley-Keswick-Weller, CNW is Clarion-Nicollet-Webster, TM is Tama- Muscatine, O is Otley-Mahaska-Taintor, C is Clinton-Keswick-Lindley soil association areas

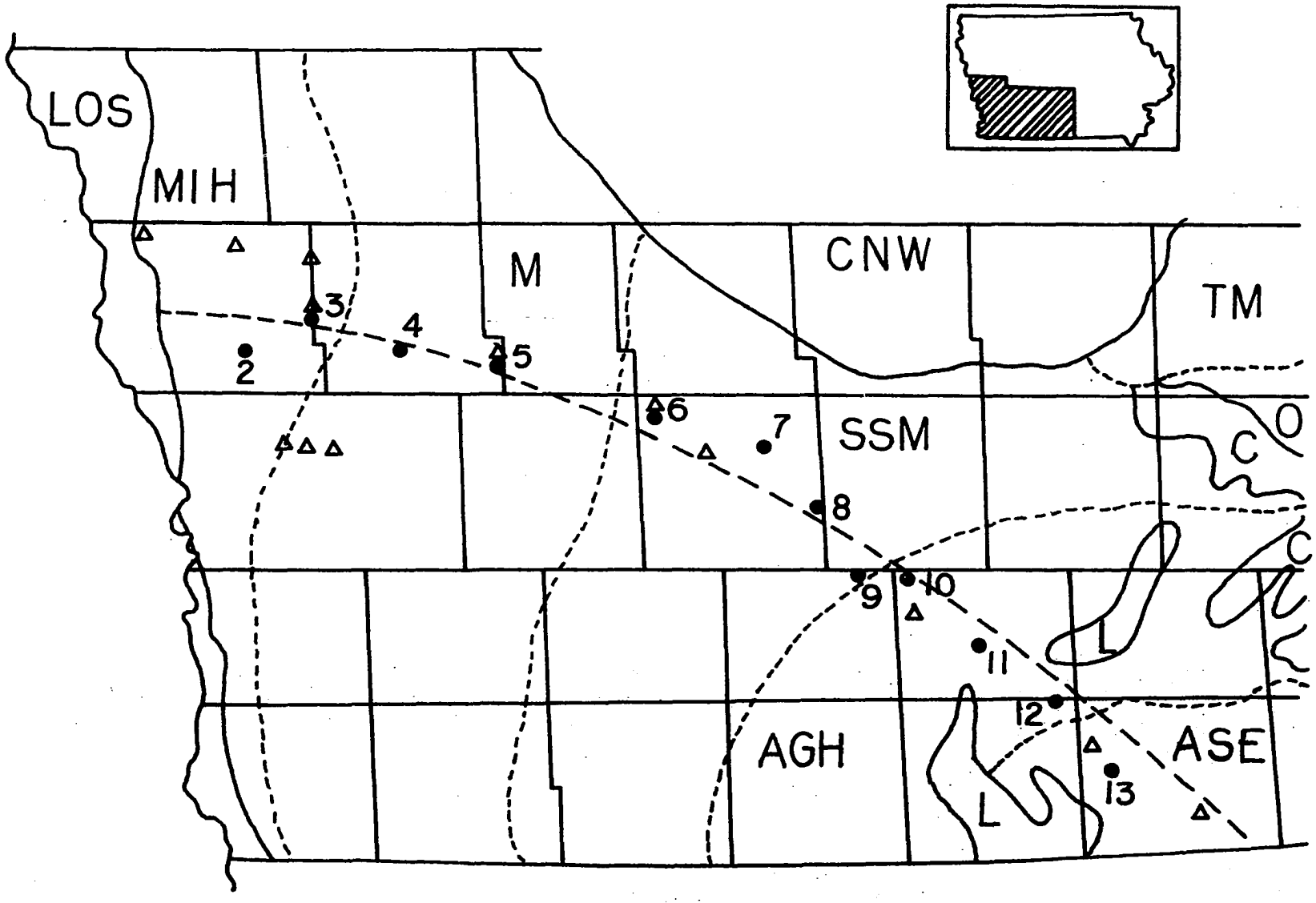

LOS
MIH
M
CNW
TM
SSM
AGH
ASE
1
2
3
4
5
6
7
8
9
10
11
12
13

Table 1. Location of individual field sites

Site No.	County	Location
02	Harrison	NW1/4 SE1/4 sec. 27, T.79N., R.42W.
03	Harrison	SE1/4 NE1/4 sec. 12, T.79N., R.41W.
04	Shelby	SW1/4 NW1/4 sec. 28, T.79N., R.38W.
05	Shelby	SE1/4 NW1/4 sec. 24, T.87N., R.37W.
06	Adair	NW1/4 NE1/4 sec. 10, T.77N., R.33W.
07	Adair	SW1/4 SW1/4 sec. 31, T.77N., R.30W.
08	Madison	SW1/4 NW1/4 sec. 31, T.75N., R.29W.
09	Union	NE1/4 SW1/4 sec.4, T.73N., R.28W.
10	Clarke	SE1/4 NW1/4 sec. 12, T.71N., R.26W.
11	Decatur	SE1/4 NE1/4 sec. 15, T.70N., R.24W.
12	Wayne	SW1/4 NW1/4 sec. 25, T.69N., R.23W.
13	Wayne	SW1/4 NE1/4 sec. 3, T.67N., R.21W.

Table 2. Field site characteristics

site no.	distance from source, miles	ave. depth, inches	ave. width, feet	soil series
2	11.7	606	175	Monona
3	20.5	538	254	Monona
4	34.7	353	518	Marshall
5	47.8	282	518	Minden
6	68.4	197	621	Sharpsburg
7	84.4	165	684	Macksburg
8	95.5	158	732	Sharpsburg
9	116.2	142	878	Winterset
10	136.7	111	1295	Haig
11	148.5	100	1744	Edina
12	160.5	93	1685	Edina
13	173.2	77	1619	Edina

Field measurements: Summit width and loess thickness

The width (W) of the stable primary divide summits of the southwestern Iowa loess province has been observed to increase with distance (D) away from the Missouri River Valley source area as W = 0.019 + 0.0076D (Ruhe, 1969a). This quantification of summit width variability was arrived at from measurements made on large scale, 50 foot contour interval, U. S. Geological Survey maps. After selection of the sites for the present study, width measurements were made by transit survey at the site. Stereoscopic pairs of aerial photographs of the area around each site were then viewed stereoscopically and further measurements were made directly from the photographs. It was noted during measurement of the aerial photographs that the edges of the summits were asymmetrically crenulated along the entire observed length. In several instances, particularly in the thick loess area of western Iowa, the summits were discontinuous. The result of these crenulations and discontinuities was a wide range in the width measurements along the length of any particular summit.

Loess thickness measurements were made using a Giddings hydraulic soil coring machine. The thickness of the loess was measured from the ground surface to the contact between the loess and the underlying Pleistocene materials. The boundaries were easily identified by the dark gray basal soil

of the Wisconsin loess and its associated black carbon flecks, by structural and textural changes and by a change in the consistence from friable or sticky loess to firm or very firm paleosols. Where exact measurement was difficult or tenuous by direct field observation, laboratory data was employed as differentia.

Several depth measurements were made from west to east across each site. Consistent depth measurements across the summit served to indicate erosional stability of the site. Morphological description of the materials encountered (Appendix B) aided in definition of the subsurface zonation in the loess and established the configuration of the underlying paleosolic Pleistocene surface.

Geohydrologic investigations

Some of the earliest investigations (Bray, 1934, 1935, 1937) into the loess provinces of the midcontinent suggested that subsurface moisture could play an important role in soil development. It was observed that the slowly permeable Illinoian till underlying the thin loess of central Illinois could have a restrictive effect on drainage (Bray, 1937). It was suggested that this could influence the relative rate of soil development, more moisture leading to a greater degree of soil development. Smith (1942) tended to discourage this concept in favor of the effective age concept. He restricted

the influence of subsurface moisture to its effect on plant growth and subsequent recycling and removal of bases and the accumulation of organic matter. When applying the effective age concept to the southwestern Iowa loess province, Hutton (1948) suggested that a high water table might exist in the loess above the gumbotil. The presence of a high water table in association with higher clay contents of the loess and loess derived soils far from the source area would be conducive to more moist conditions during soil development and at present (Hutton, 1948).

The existence of ground-water tables perched on the dense paleosols underlying the loess was based on incidental observation and thus not strongly considered as an influencing factor. Ruhe (1969a) discussed in considerable detail the implications and possible significance of this perched ground-water table. In his discussion, he utilized Ulrich's porosity data (1949)and rainfall data to calculate possible heights of ground-water zones in the loess. Since the thickness of the loess, and hence the depth to the paleosol, decreased with distance, the ground-water table came closer to the surface, and indeed into the soil solum further from the loess source area. These stratigraphic implications in association with the topographic conditions of wider summits and decreasing local relief lead Ruhe to propose that the more moist conditions further from the source

area were very important in soil development.

On the basis of the historical development of groundwater considerations and the re-emphasis given by Ruhe (1969a), ground-water table measurements were deemed essential to an explanation of the possible influence of groundwater cn soil development in the southwestern Iowa loess province. This phase of the investigation takes on particular significance when the radiocarbon chronology of the loess as developed in Iowa (Ruhe, 1969a) appears to be contradictory tc the presently accepted effective age concept.

Six of the summit sites were chosen for detailed gechydrological investigation (Figure 1). The sites were chosen to occur in the middle of each of the soil association areas crossed by the traverse. However, since the Shelby-Sharpsburg-Macksburg soil association area is extremely wide where the traverse crosses through it, two summits were chosen to occur approximately one third of the width of the area from each boundary. This equally divided the area and maintained nearly uniform hydrologic site spacing across the traverse.

The hydraulic scil coring machine was used to drill a 1 3/4 inch diameter hole as clcse as possible to the center of each of these six sites. Black steel pipe, two inches in diameter was driven down these holes with a standard, 140 pound hammer as described by Spangler (1960). Drive points

were constructed for the casings of the same pipe. Four slots were cut back with an acetylene torch six inches from the end. The pipe was then heated and the point pounded closed and tapered. Six inch slots were cut in the wall of the pipe in a spiral pattern extending back two feet from the point. This provided a closed, tapered point to facilitate driving the casing and six open slots in the wall of the casing for free water access to the interior of the well. The casing was assembled as it was driven down the predrilled hole and driving was stopped when the casing was at the surface of the underlying material.

With the casings thus constructed and driven to the thickness of the loess, the level of any zone of saturation in the loess and above the underlying paleosol would be reflected by the water level in the casing. To record this water level, Stevens model F-60 water level recorders were installed on each well (Fryrear, 1969). This provided continuous monitoring of water table fluctuations throughout the calendar year and at each location of differing loess thickness simultaneously.

Laboratory Methodology

One core from each field site was saved for laboratory analysis. These cores were selected from the center of each summit to be representative of the entire summit as deter-

mined by the drilling program previously described. Each core was subsampled in five inch increments or by morphologic differences which ever was smaller. After air-drying, all samples were ground in a non-ferrous grinder to pass a 2mm sieve and saved for analysis.

Mechanical analysis

Particle size distribution of the air dry, <2mm samples was determined by a modification of the method of Kilmer and Alexander (1949). A 20 gram sample was placed in a 100 ml beaker and moistened with 20 ml of distilled water. The resultant suspension was allowed to equilibrate for 30 minutes with occasional stirring and the pH measured by a glass electrode. The suspension was then transferred to a pyrex baby bottle and diluted to 100 ml. To this was added 10 ml 1% acetic acid and 20 ml 30% hydrogen peroxide. The mixture was heated slowly on a sand table and finally boiled vigcrously to remove the excess hydrogen peroxide not required for the oxidation of crganic matter. Twenty ml Calgon-sodium carbonate solution was added to the suspension and it was brought to 150 ml volume with distilled water for shaking overnight on a reciprocating shaker. Following this, the suspension was transferred to a 1000 ml cyclinder and brought to volume with distilled water. The samples were vigorously stirred by hand in the cylinders and pipetted in

the Wentworth (1922) scale at settling times calculated from the nomographs of Tanner and Jackson (1947). The size scale was modified to include finer fractions. The finest fraction, < 0.5 micron diameter, was separated by centrifugation of a sample pipetted from the cyclinder at the time of the final 0.5 to 1.0 micron sampling. The sand fraction was collected by washing the entire contents of the cylinder through a 61 micron sieve after all pipetting was completed.

Determination of carbon distribution

Calcium carbonate was determined by the method of gravimetric loss of carbon dioxide (Richards, 1954). Five grams of air-dry soil was added to a weighed 50 ml erlenmeyer flask containing 10 ml 3N hydrochloric acid. A stopper was set loosely in the flask and the contents gently swirled and set aside until effervesence ceased. The reaction was usually complete in one hour at which time the flask, stopper, and contents were weighed to determine the weight loss. A blank correction was made to compensate for evaporative losses and the calcium carbonate equivalent was calculated.

Total carbon was run by the Leco 70-second carbon analyzer method (Tabatabai and Bremner, 1970). The instrument used was a Leco Model 521 high-frequency induction furnace connected to a Leco Model 750 - 100 automatic 70-second carbon analyzer. A 0.25 gram sample of air-dry, < 2 mm

soil was placed in a Leco #528-035 crucible and covered with one scoop (ca. 1 gram) of iron chips (Leco #501-077), one scoop (ca. 1 gram) of tin (Leco #501-076) and one scoop of tin-coated copper (Leco #501-263). The accelerator treated sample was analyzed according to the instruction manual for the instrument.

Ruhe (1969a) reports that, in the thick loess of southwestern Iowa, the organic carbon content of the loess is only a trace. Morphologic description of the loess (Appendix B) indicates from color changes that organic carbon is restricted to the solum and leached portion of the loess both above and below the calcareous material. Therefore, the total carbon analysis of the leached loess was interpreted as organic carbon and the calcium carbonate equivalent determined in the calcareous loess was interpreted as the total carbon content of that material.

Determination of free iron and manganese

Free iron and free manganese were determined by atomic absorption spectroscopy from extracts prepared according to Holmgren's method (1967). Four grams of air-dry, < 2 mm soil was weighed into a pyrex baby bottle. Two grams of sodium dithionite, 20 grams of sodium citrate and 150 ml distilled water were added and the mixture shaken overnight on a reciprocating shaker. Ten drops of 0.2% solution of

superfloc was added and the volume adjusted to 200 ml. After a 30 minute settling time, 4 ml of supernatant was pipetted into a 100 ml volumetric flask. This was brought to volume with distilled water and the solution saved in a 2 ounce plastic bottle for analysis. Standards of 2, 4, 6, 8, 10, 12 and 20 ppm iron were prepared from pure iron wire. The samples were analyzed on a Perkin-Elmer atomic absorption spectrophotometer. The reading from the instrument was converted to ppm iron from the standard curve and to percent free iron by multiplying the ppm iron by 0.125.

For the free manganese determination, a 25 ml aliquot of the extract was pipetted into a 100 ml volumetric flask and brought to volume with distilled water. The samples were saved in 2 ounce plastic bottles. Manganese standards were prepared from pure manganese metal in concentrations of 1, 2, 3, 4, 5, 6, 8, 10 and 12 ppm. The readings from the atomic absorption instrument were converted to ppm from the standard curve and to percent free manganese by multiplying by 0.02.

Mineralogical analysis

In accordance with previous investigations, the mineralogical investigations were conducted on the size fractions suspected of showing alteration due to weathering. The sand size fraction, > 62 microns diameter, was examined for the occurrence of secondary ferro-manganiferrous concretions

(Bray, 1934) and the clay size fractions, < 2 microns diameter, for silicate mineral distribution and alteration.

The sand-size fraction obtained from sieving during mechanical analysis was saved for optical observation. Low magnification stereo-microscopic grain counts were made on loose, dry material spread in a counting tray. A minimum of 350 grains were counted in each sample. Secondary iron-manganese concretions were identified as rounded, reddish, yellow, black or brown concretions. The surface of these concretions exhibited a dull, non-metallic luster with no preferred fracture evident. The remainder of the sand-size grains exhibited a vitreous or adamantine luster and distinct cleavage. These minerals were considered to be primary minerals and as such, part of the depositional system. Where evident, mica, also considered a primary mineral, was counted seperately.

The analysis of the silicate minerals in the clay size range was conducted by X-ray diffraction methods. Twenty gram samples of soil were treated exactly as samples prepared for mechanical analysis. Samples were pipetted at 2 micron diameter limits. Two 25 ml samples were combined and stored in 1% formaldehyde solution to retard microbial growth during storage. Separation into three size fractions, < 0.5 microns, 0.5 to 1.0 microns and 1 to 2 microns diameter, was accomplished by centrifugation. The resulting fractions were

mounted on porous ceramic plates under vacuum to give oriented mounts. The mount was then leached three times with 1N magnesium chloride to magnesium saturate the exchange complex and provide diagnostic diffraction diagrams. Excess salts were removed by leaching these three times with distilled water. The mounts were then air-dried and glycerol solvated. A General Electric XRD-6 X-ray diffractometer was used with copper radiation for analysis of the mounts. Diagnostic diffraction peaks were identified from the tables presented in Brown (1961).

RESULTS AND DISCUSSION

It was realized from the outset of this investigation that a multidisciplined approach was necessary to evaluate the interrelated complexities of the southwestern Iowa loess-soil system. The fields of pedology, geomorphology, geochronology and gechydrology formed the basic foundation for the study and were supplemented by many other areas of specialization where necessary. Since one objective of this study was quantification of the loess system itself, field study methods were rigorously employed to define the physical system on the present landscape. These methods were supported and complimented by laboratory analysis. The final integration of field and laboratory data was used to quantitatively define the natural system involved. The general approach to the study then has been from the initial field study to the laboratory and finally a fitting of the products of the first two phases back to the naturally occurring system of loess-soil-landscape, inextricably interrelated.

Field Measurements

The field investigation phase of this study has been described in detail in the preceding chapter. Since the entire study was conducted on a natural system, it was essential that the occurrence of this system on the landscape be carefully investigated. This involved evaluation of geomorphic,

stratigraphic, geohydrologic and pedologic conditions and the interrelationships between them.

Geomorphic and chronologic relations

The geomorphic setting for this study was a series of primary upland divides between major drainageways in southwestern Iowa. Each site was chosen, as previously described, to represent the distributional thickness of the loess with minimal or no erosional modification of that section of the landscape. Since each site occurred with less than two percent slope from the horizontal, it was felt that erosional removal of loess would be negligible. A series of transverse summit width measurements with very little deviation from mean measures verified these assumptions concerning stability.

Summit width was measured as previously discussed by rod and transit survey and stereoscopic measurement on aerial photographs. While locating the field sites and when making width measurements, it was observed that, in the area of thickest loess accumulations near the Missouri River Valley, the divides were asymmetrically crenulated and in many instances even discontinuous. This appears to be the result of erosion and not deposition. The present surface of these side slopes truncates weathering zones in the loess and must therefore be post-depositional surfaces. Eastward from the

source area, there are fewer discontinuities but the assymetric crenulation of the edges of the divide summits remains evident.

The width of these summits was regressed against distance from the source area (Figure 2). A positive correlation coefficient of 0.9076, significant at the one percent level, indicates a close relationship between summit width and distance. The regression equation explains 83 percent of the variability encountered in the data.

Observations of many road-cuts in the research area provided some insight into the increase in summit width and distance from the Missouri River Valley. Nearest the valley where the summits are narrow and rounded, local relief is great. The loess lies unconformably on the paleosolic surfaces thus obliterating this pre-existing surface and reflecting only the influences of deposition and subsequent modification by erosional processes. As distance increases, the summits become considerably wider and assume the configuration of the underlying paleosolic surfaces. The amount of local relief appears to decrease and the summits become much flatter. The combination of shorter slope lengths from decreased local relief (Ruhe, 1969a) and wider and flatter summits could possibly decrease the amount of erosional energy from rainfall runoff. This could explain in part why erosional modification of the landscape is more apparent in

the thick loess areas. In addition, the distributional feature of increasing summit width would mean that, in order to erode away portions of the wide, flat summits and create a discontinuous divide pattern, a considerably greater amount of erosion over a horizontal distance would have to occur than where summits are naturally narrow and rounded.

At the same time summits are becoming wider, loess thickness is decreasing systematically (Figure 3). The regression equation which best fit the data was a hyperbolic function with a correlation coefficient of -0.990. This equation explains 98 percent of the variability of the data. Loess thickness decreases very systematically with distance away from the source area. It should be emphasized that this equation and the constants involved in no way explain loess thickness variation at all places. The equation fits the data of this particular investigation and shows that thickness is very systematic within the study area and can be predicted with considerable accuracy along the traverse.

This equation is a marked departure from previous quantifications of loess thickness which were essentially exponential equations (Smith, 1942; Hutton, 1948; Ulrich, 1949). These previous investigations employed road-cuts, where available supplemented by hand augering equipment to compile thickness data. The hydraulic soil coring machine utilized in this study permitted many measurements at each

Figure 2. Relationship between the width of stable primary divide summits and distance from the loess source area

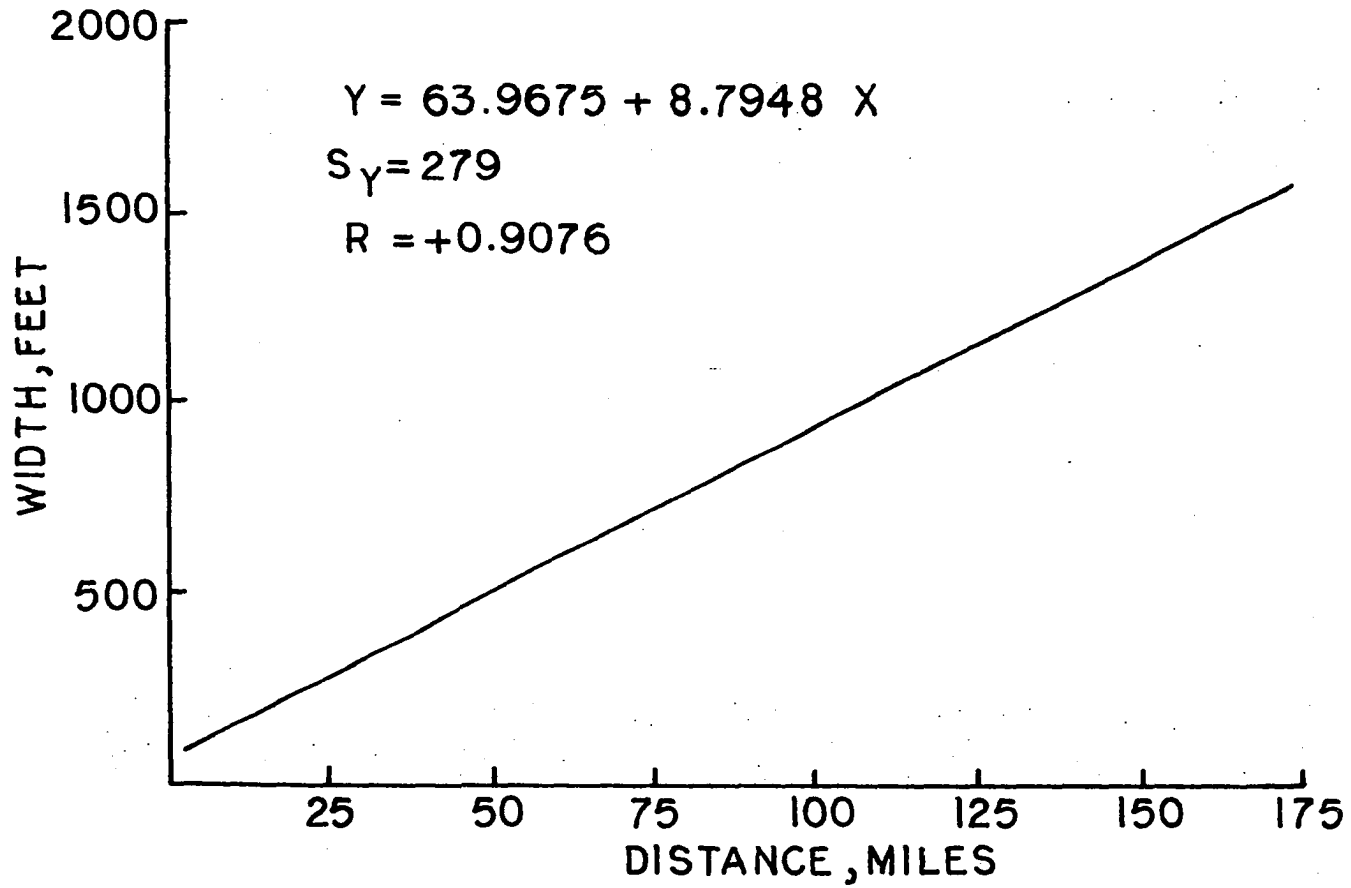
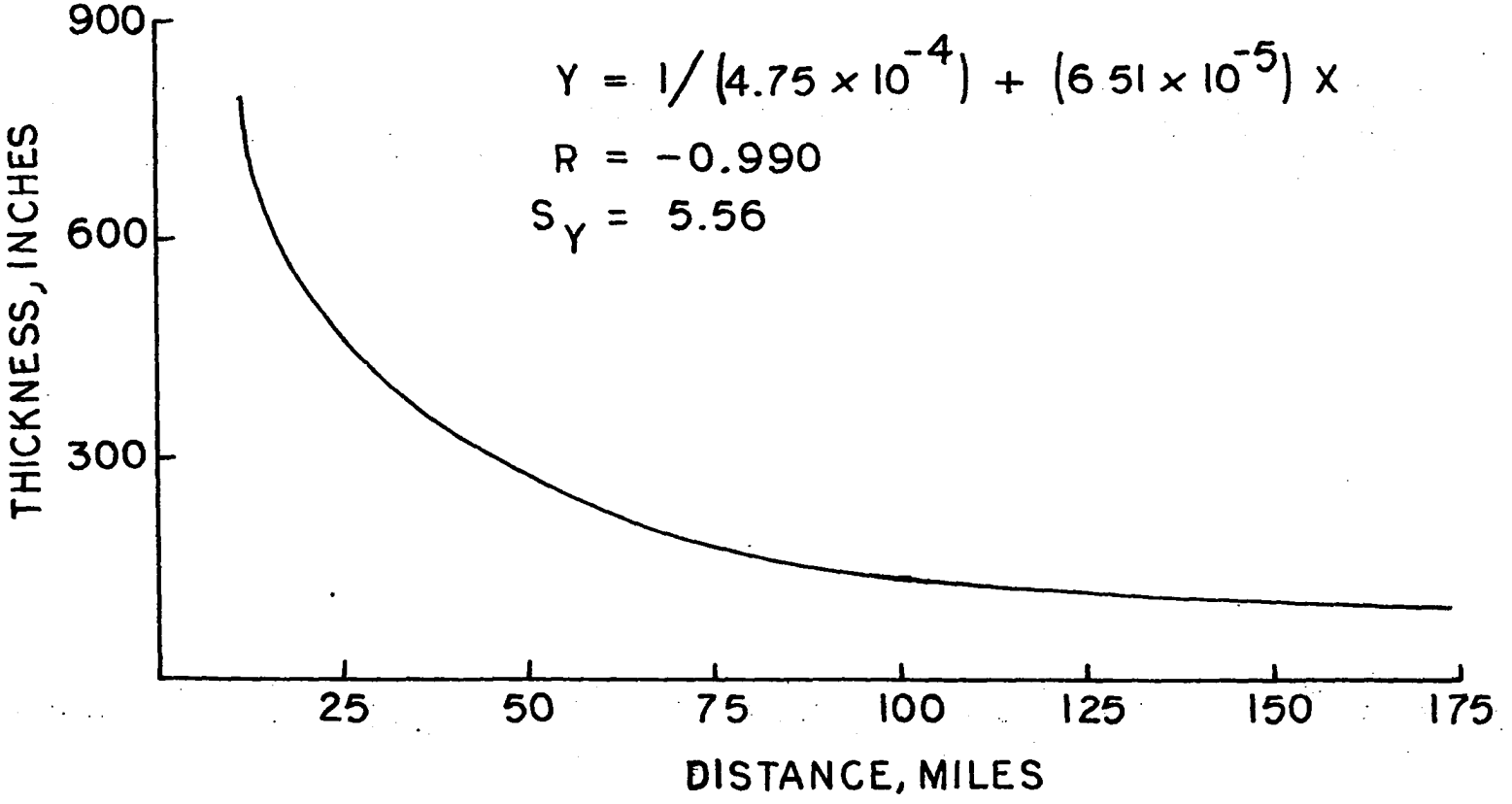

Y = 63.9675 + 8.7948 X
S_Y = 279
R = +0.9076
2000
1500
1000
500
WIDTH, FEET
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 3. Relationship between the thickness of loess on primary divides and distance from the loess source area


900
600
300
THICKNESS, INCHES
$Y = 1/(4.75 \times 10^{-4}) + (6.51 \times 10^{-5})\ X$
$R = -0.990$
$S_Y = 5.56$
25
50
75
100
125
150
175
DISTANCE, MILES

carefully selected site on the landscape. Also, the earlier investigators established straight line traverses felt to represent depositional wind directions. The curvilinear alignment of this traverse was based on loess thickness contours and as such should be more representative of depositional patterns. The combination of better representation of the vectorial properties of deposition and more measurements of loess thickness on carefully selected, and essentially uneroded, sites lends a greater degree of confidence to the present functional relationships derived between distance and thickness of loess.

Previous assessments of the loess-soil-systems of the mid-continent have become involved in estimation of the time factor by means of carbonate mineral removal by leaching and the degree of soil development as reflected in soil morphology. Smith (1942) states unequivocally that both the time and rate of loess deposition were uniform at all places which he studied in Illinois. Both Hutton (1948) and Ulrich (1949) concurred with this evaluation of time and all three investigators arrived at the effective age concept to explain differences in the loess derived soils which they studied. The assumption of uniform rate and time of deposition is essential to the acceptance of this concept. The advent of radiocarbon dating techniques permitted placement of the loess system into an absolute time scale and resulted in the obser-

vation of discrepancies between the effective age concept assumptions concerning time and the actual values.

Many radiocarbon dates are available within the state of Iowa (Ruhe, 1969a). Several of these dates have been selected from previous works and supplemented by more from this study to give a composite picture of loess deposition within an absolute time framework. A total of fourteen dates have been employed to arrive at the relationship shown in Figure 4.

Where the loess of southwestern Iowa passes under the Cary till of central Iowa, Ruhe and Scholtes (1956) have radiocarbon dated the contact at 14,000 Y. B. P. This date would mark the earliest time of Cary ice advance and similarly, the latest possible date for the cessation of deposition of the underlying Wisconsin loess. It follows from this that, on the most stable positions on the loess landscape of southwestern Iowa, that the surfaces can be no younger than 14,000 Y. B. P. This extrapolation must be carried throughout the southwestern Iowa loess province and applied to the stable summit positions chosen for this study.

The basal soil of the Wisconsin loess provides an abundance of carbon for radiocarbon dating the initiation of loess deposition (Appendix C). The relationship between the radiocarbon age of the basal soil and distance from the loess source area is shown in Figure 4. The linear equation agrees

with previous quantification (Ruhe, 1969a, 1969b) but differs in the constants. This equation is based on more observations than earlier publications. The correlation coefficient of 0.62 is statistically significant at the one percent level. The age of the basal soil, and consequently the time of initiation of loess deposition, can be calculated at 23,270 Y. B. P. next to the Missouri River Valley and at 18,320 Y. B. P. 175 miles away. Actual radiocarbon dates of the basal soil at these approximate locations are 23,300 ± 550 Y. B. P. (I-5107) at the bluffs and 19,200 ± 900 Y. B. P. (I-1408) on the eastern end of the traverse. Thus, deposition of loess closest the source area extended from 23,270 to 14,000 Y. B. P., a period of 9270 years, and from 18,320 to 14,000 Y. B. P. 175 miles away, a period of 4320 years. Similar relationships can be calculated at different points along the traverse.

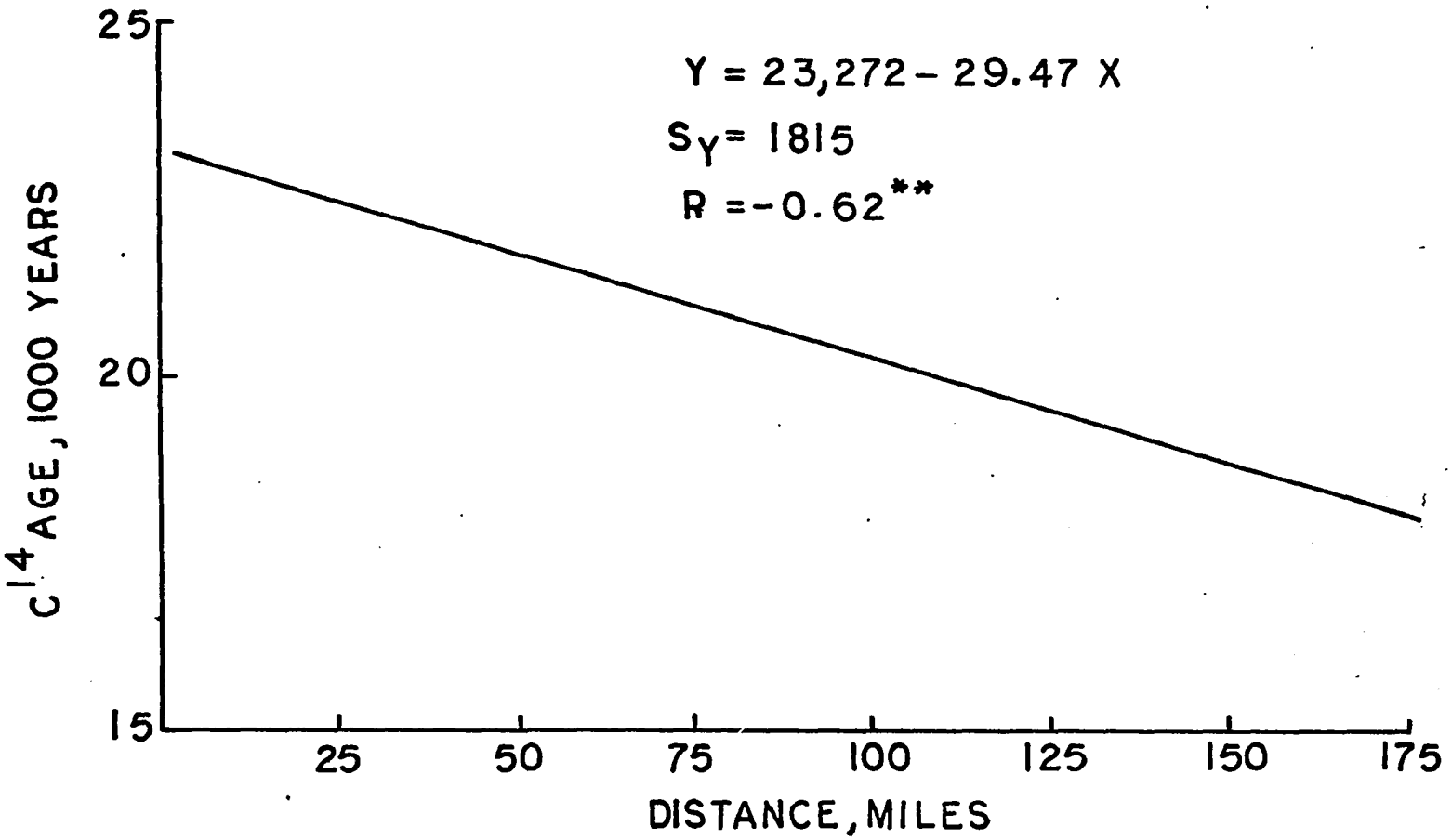
Contrary to the effective age concept, the age of the loess differs with distance and is in fact a time-transgressing zone encompassing all of Farmdale and part of Tazewell time units. Sedimentologically then, loess deposition appears to have the characteristics of overlap. Under these depositional conditions, successive younger increments of Wisconsin loess overlap previous increments and in this manner, the basal soil must and does become younger with increasing distance from the source area. The established con-

dition of sedimentolcgic overlap combined with radiocarbon chronolcgy of the basal soil substantially refutes the uniform age of loess assumption basic to the effective age concept.

One other basic assumption made by Smith (1942) was that during deposition, the rate cf accumulation of the loess was ccnstant at any particular point alcng a traverse. Ruhe (1969b) presents radiocarbon dates from the basal soil and from "dark bands" within the loess and from these calculates possible rates of accumulation. In southwestern Iowa, the basal soil was radiocarbon dated at 24,750 ± 700 Y. B. P. (I-3870) and a dark band containing 0.279 percent carbon 3.3 feet above this was dated at 19,250 ± 400 Y. B. P. (I-3703). Between these dated zones, the rate of accumulation was calculated to be 0.6 x 10^{-3} feet per year. Another band, 27.3 feet above the first was dated at 15,300 ± 300 Y. B. P. (I-4029). This produced a calculated rate of 6.9 x 10^{-3} feet per year, nearly a twelve-fold increase in rate. Obviously then, rates of deposition and accumulation have varied over time.

Mention should be made at this time however of an error in interpretation in the forementioned publication. Sample I-3703 was collected from a single on-site drilling and was interpreted as the basal soil with an overlying dark band. Further drilling on this site indicated this to have been an

Figure 4. Relationship between radiocarbon age of the basal soil of the Wisconsin loess and distance from the loess source area


Y = 23,272 – 29.47 X
S_Y = 1815
R = –0.62**
C^{14} AGE, 1000 YEARS
25
20
15
25
50
75
100
125
150
175
DISTANCE, MILES

erroneous interpretation. Figure 5 presents the actual system encountered as determined by drilling. Where this radiocarbon sample was taken was in fact not a dark band as they are normally defined (Daniels et al., 1960), but rather appears to be a gully fill on the pre-existing landscape. If this is true, as it appears to be, then Ruhes' interpretation of a period of landscape stability during a period of non-deposition is in error. A more accurate evaluation would be slow accumulation of the basal soil as dated at 24,750 Y. B. P. followed by a period of erosional activity which terminated at 19,250 Y. B. P. when deposition commenced again. During this period of 5500 years, organic matter accumulated in the first loess increments, but these were subsequently removed by erosion and were redeposited in this case as a gully fill 3.3 feet thick. On the present land surface and facing southeastward away from the radiocarbon site, is a gully apparently controlled by a gully in the paleosolic surface which is clearly exposed and evident further down slope. The axis of the earlier gully and the concurrent present gully align perfectly with the radiocarbon site on the summit. In light of this discussion, Ruhe's rate of accumulation of 0.6×10^{-3} feet per year must be seriously questioned, even though the complete situation was not realized until after publication of this data. However, his conclusion that rates of deposition were variable remains valid.

In fact, pericds of non-deposition existed, in this case even accompanied by periods of erosional activity.

The absence of the basal soil on side slopes has previously been interpreted as evidence of erosional activity during loess deposition. It may now be stated rather conclusively that during slow deposition of the initial loess increments, there were periods of erosional activity during which loess was stripped from the less stable positions on the landscape but this loess may have been in place long enough to have accumulated considerable organic carbon.

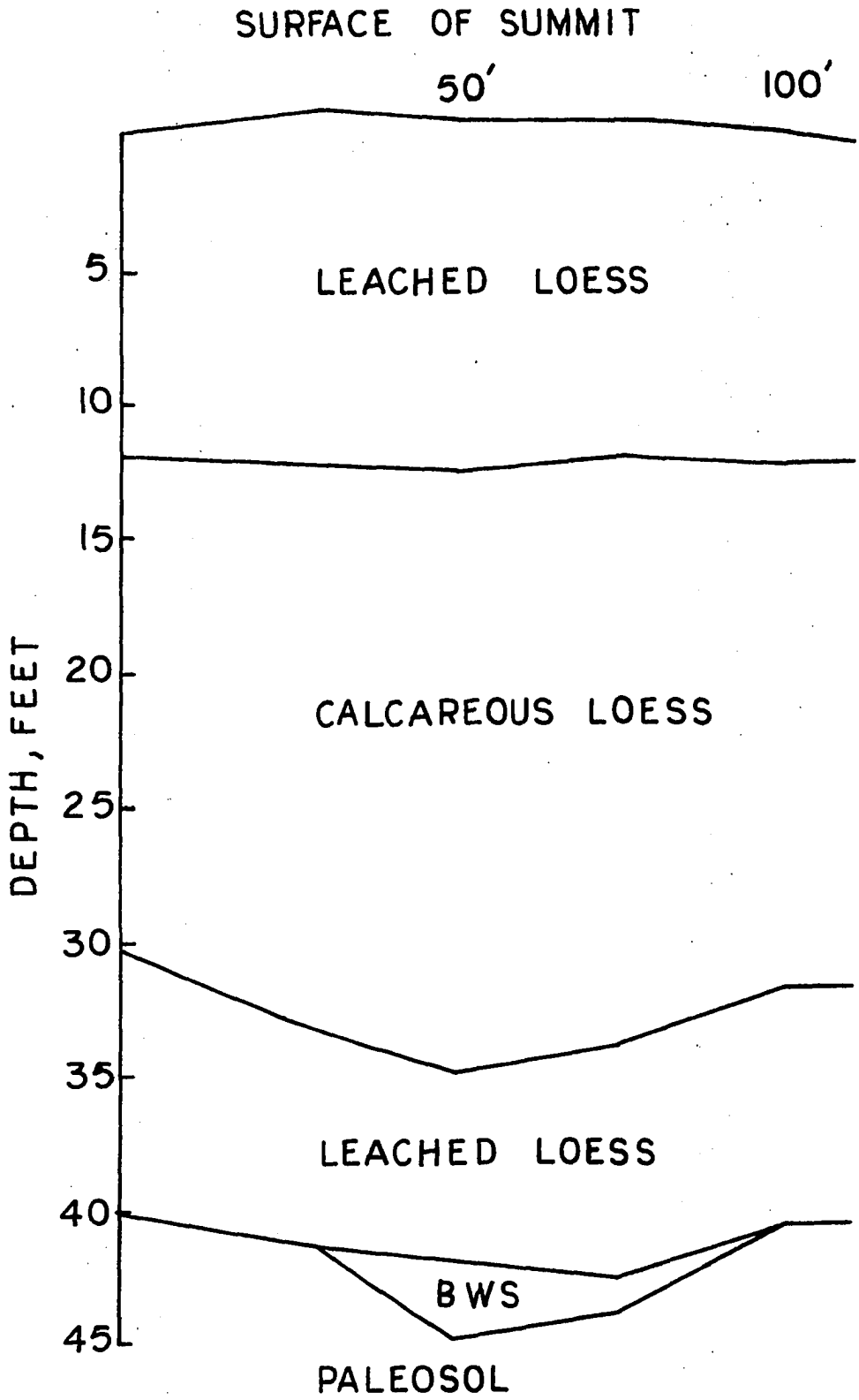
Such errors in interpretation of radiocarbon sections and indeed of much subsurface exploration can and should be avoided by intensive examination of the entire system under investigation.

The final conclusion reached based on actual radiocarbon dating cf the loess is that the basic assumptions employed in derivation of the effective age concept were erroneous. Therefore the entire loess-soil system must be re-evaluated and placed in a more accurate chronologic and pedologic setting. The remainder of this thesis will be devoted to this rather ambitious undertaking.

Hydrologic conditions

The equation in Figure 3 relating loess thickness to distance from the source area similarly describes the rate of approach of the underlying paleosolic surface to the present

Figure 5. Cross section of site number three showing leached loess, calcareous loess, leached loess over the basal soil of the Wisconsin loess (BWS) occurring as a gully fill on the Sangamon paleosol


SURFACE OF SUMMIT
50'
100'
5
10
15
20
25
30
35
40
45
DEPTH, FEET
LEACHED LOESS
CALCAREOUS LOESS
LEACHED LOESS
BWS
PALEOSOL

surface. The existence of this paleosol has been related to a perched zone of ground-water in the overlying loess (Kunkle, 1968; Vreeken, 1968). These paleosols, in southwestern Iowa, are the Sangamon paleosol extending eastward approximately 55 miles from the Missouri River Valley (Ruhe et al., 1967) and the Yarmouth-Sangamon paleosol, gumbotil, under the remainder of the loess eastward. Both of these paleosols have heavy, clayey sola (Ruhe, 1969b) and as such create the perched zone of saturation in the loess. As the loess thins and the paleosols concurrently become closer to the surface of the loess, any zone of saturation present must also come closer to the loess surface.

The extent of these ground-water zones was monitored throughout the present study by the use of water level recorders installed on piezometric-type wells as described earlier. The location of sites with wells is shown in Figure 1. During the drilling phase of the field program, it was observed that, with increasing depth into the loess and approaching the paleosol, there was a marked increase in the moisture content of the loess. Immediately superjacent to the paleosol in every instance, there did exist a zone of saturated loess as evidenced by free water standing in the drill hole. Careful observation revealed that the underlying paleosol was in fact, relatively dry. Similar situations have been reported in central Iowa (Kunkle, 1968; Vreeken,

1968) and suggested for southwestern Iowa (Ruhe, 1969b).

The results of two years measurements can, in no way, be considered as sufficient for hydrologic data interpretation. However, measurements were consistent enough throughout this period of time to permit establishment of apparent geomorphic-hydrologic-stratigraphic relationships. These relationships are shown in Figure 6. Previous assumptions concerning the water-table approaching the ground surface have been correct. The shape of the curve, although logarithmic, is similar to the shape of the loess thickness distribution curve. There is an obvious relationship between these measurements as described by the regression equation Y = 0.0986X - 61.92 and shown graphically in Figure 1. This equation states that as the loess thickness (x) decreases, the depth to the water-table (Y) decreases. The standard deviation is ±13.00 inches and a correlation coefficient of +0.9977 is significant at the one percent level. The equation accounts for 99.54 percent of the variability of the data.

It can be calculated that if the loess of southwestern Iowa reached a thickness of 5 ± 1.0 feet, the water-table would be very nearly at the ground surface. On the eastern end of the traverse, the underlying Yarmouth-Sangamon paleosol outcrops high on the side slopes and immediately above it, a seepage zone normally occurs. This seep zone

Figure 6. Relationship between depth to perched water-table and distance from the loess source area

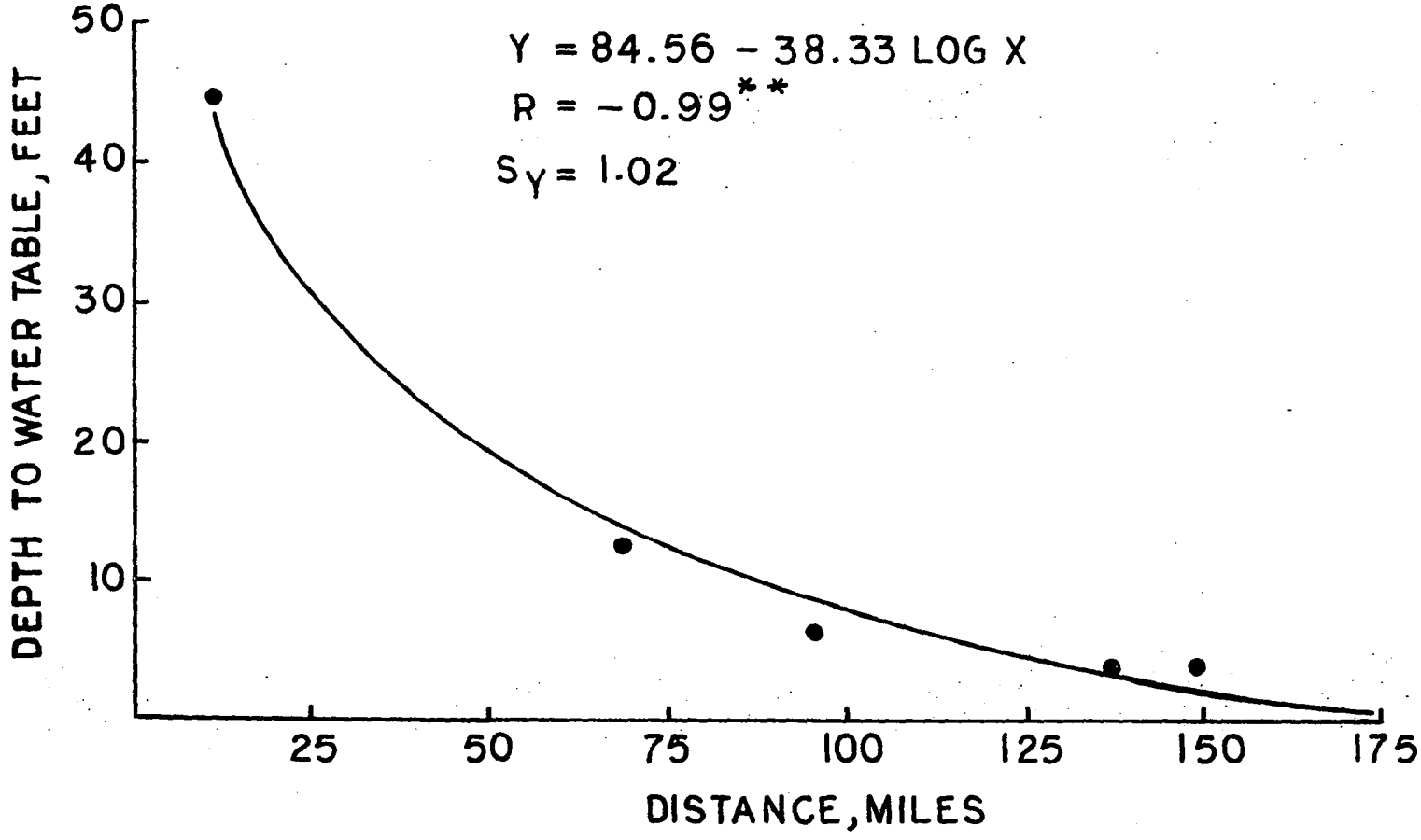
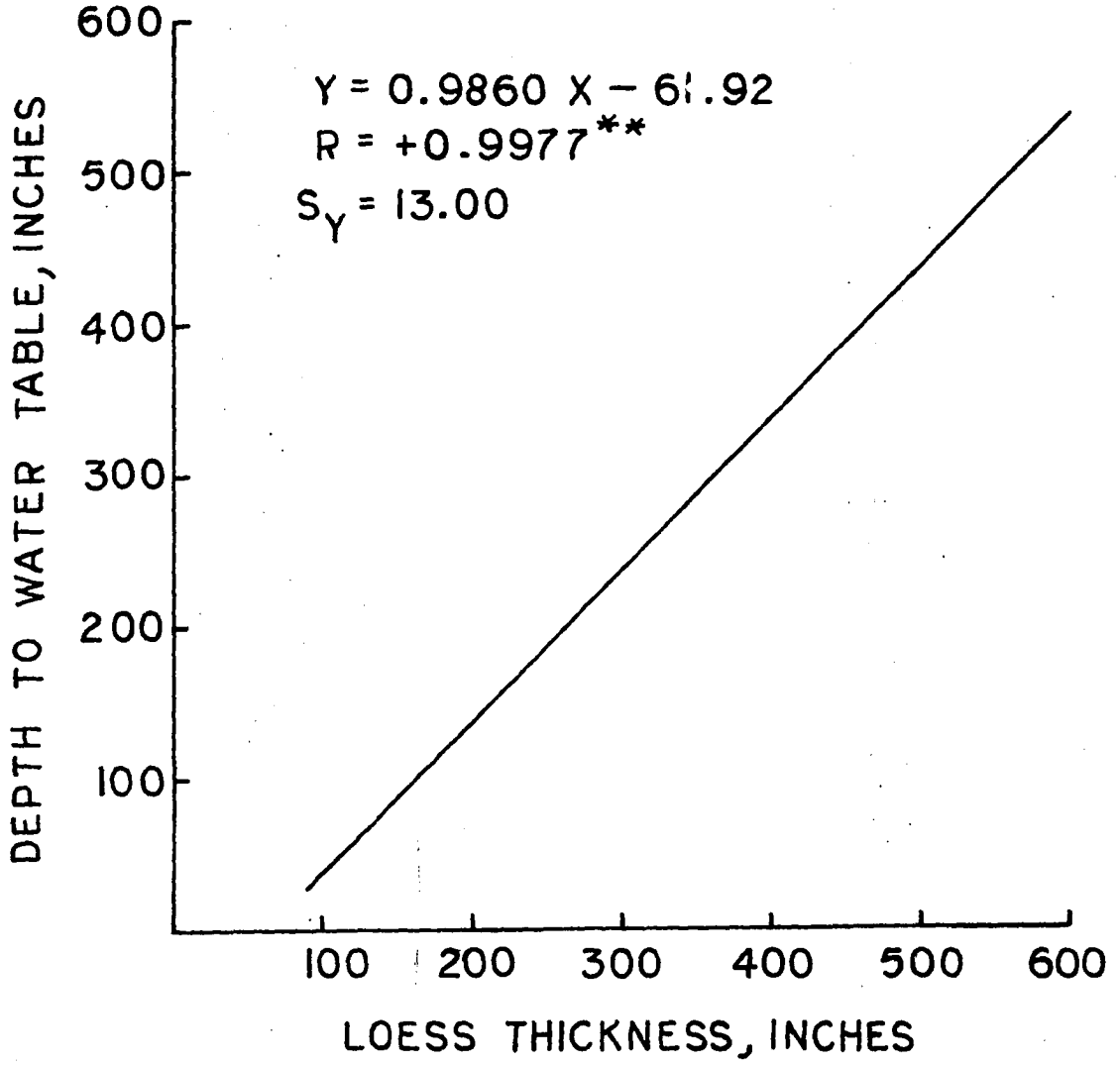

Y = 84.56 - 38.33 LOG X
R = -0.99**
Sy = 1.02
DEPTH TO WATER TABLE, FEET
50
40
30
20
10
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 7. Relationship between loess thickness and depth to perched water-table


Y = 0.9860 X − 61.92
R = +0.9977**
S_Y = 13.00
DEPTH TO WATER TABLE, INCHES
600
500
400
300
200
100
100
200
300
400
500
600
LOESS THICKNESS, INCHES

would seem to coincide with the calculated thickness necessary to have saturation at or very near the surface.

Ruhe (1969a) developed several relationships between properties of the loess-soil system and distance from the source area. Many of these relationships were best described by bipartite functions. In each instance discussed, the break in the curve occurred at a loess thickness of 160 inches, by the present thickness distribution equation, a distance of 100 miles from the Missouri River Valley. One of these relationships is that between distance and depth to the deoxidized zone, this zone approaching very close to the present surface at a loess thickness of 160 inches. The morpholcgical expression of the deoxidized zone may be masked by the soil solum and therefore not apparent. Ruhe's (1969a, 1969b) interpretation of the deoxidized zone as a relict feature of a previous zcne of saturation would appear to be reasonable based on the hydrologic relationships established in this investigation indicating that the zone of saturation rises, at an average level, to the base of the solum of the scil at a loess thickness of 158 inches. Further east along the traverse, the water-table rises well into the solum of the soil and in fact remains in the solum throughout the year.

At the same thickness of 160 inches, Ruhe (1969a) reports a bipartite functional relationship between the clay

size fractions in the B horizon and distance. Obviously, this is coincident with the thickness of loess associated with saturation or moistening of the solum by ground-water. The significance of this will be discussed in detail during the following discussion of particle size distribution and parent material composition.

A multiplicity of factors contribute to the height of rise of the zone of saturation in the loess. These factors also contribute significantly to the constancy of the level of rise as seen in the hydrographs in Appendix D. The rainfall is essentially uniform across the loess province, ranging from 30 to 34 inches annually from west to east (Ruhe, 1969a). These values are averages and do not represent any particular year. However, it may be concluded that an average difference of 4 inches per year would not contribute significantly to changes and differences in ground-water regimes across a distance of 175 miles. It is felt that geomorphic, stratigraphic and sedimentologic factors exert a greater influence.

Given approximately uniform rainfall throughout the loess province, attention must turn to stratigraphy to explain the existing zone of saturation. As prevoiusly discussed, the paleosols are buried at less and less depth by the loess from west to east and can therefore be related directly to the presence of the zone of saturation as the

stratigraphically identifiable, impermeable barrier to deeper ground-water percolation. The geomorphic conformation of the summits is another major contributing factor. From west to east, the summits become wider and flatter. Rainfall incident upon the slightly rounded, narrow summits on the western end of the traverse can produce as much runoff as infiltration (Beer et al., 1966). However, rainfall incident upon the very wide, extremely flat summits on the eastern end has no real opportunity to runoff and essentially all the rain must percolate into the loess. This water then remains perched on the impermeable paleosols. Once the water is stored in the loess, it has two options for removal. The first is by evapotransporation. Where the loess is thick, this can be excluded since plant roots would rarely if ever reach the water table and evaporation from great depths is negligible. However, where the loess is thin, evapotransporation would be important. The second option for removal of the perched water would be by lateral seepage. Where the loess is thick, the summits are narrow and water could move laterally along a paleosolic surface to form side slope seepage zones. These are observed in thick and thin loess areas. Where the loess is thin, however, the moisture would have to travel great distances under a very slight hydraulic gradient. Therefore, where the loess is thick, the gradient would be greatest and the lateral distance smallest.

Where the loess is thin, the lateral gradient would be small and distances great.

One other factor, a combination of sedimentology and pedcloqic considerations would have a great influence on water storage and subsequent movement. From west to east in the loess province, bulk density and capillary porosity increase while aeration porosity decreases (Ulrich, 1949). Under the stratiqraphic and geomorphic conditions enhancing the accumulation of water and influencing its movement, the conditicns of decreasing aeration porosity and consequent increasing capillary pcrosity would further restrict lateral internal removal of water.

The porosity of the underlying paleosolic surfaces combined with the sedimentologic and gecmorphic conditions of the summits can be seen to ccntrol the depth of the perched water-table. This accumulatien is further confounded by decreasinq permeability and consequent increasing storage capacity in the capillary pore spaces. The result of these characteristics of the loess province was reflected in the increasing height of the perched zone of saturation in the lcess. The presence of this zone will be introduced later to place emphasis on its occurrence and its significance in a pedologic interpretatien of the southwestern Iowa loess province and associated soils.

Laboratory Measurements

The methodology employed in the laboratory has been fully described and referenced in the preceding section. The various determinations made were selected to characterize the soil and the loess from which it developed in addition to measuring changes in these materials from a sedimentologic and pedologic standpoint.

Carbon distribution

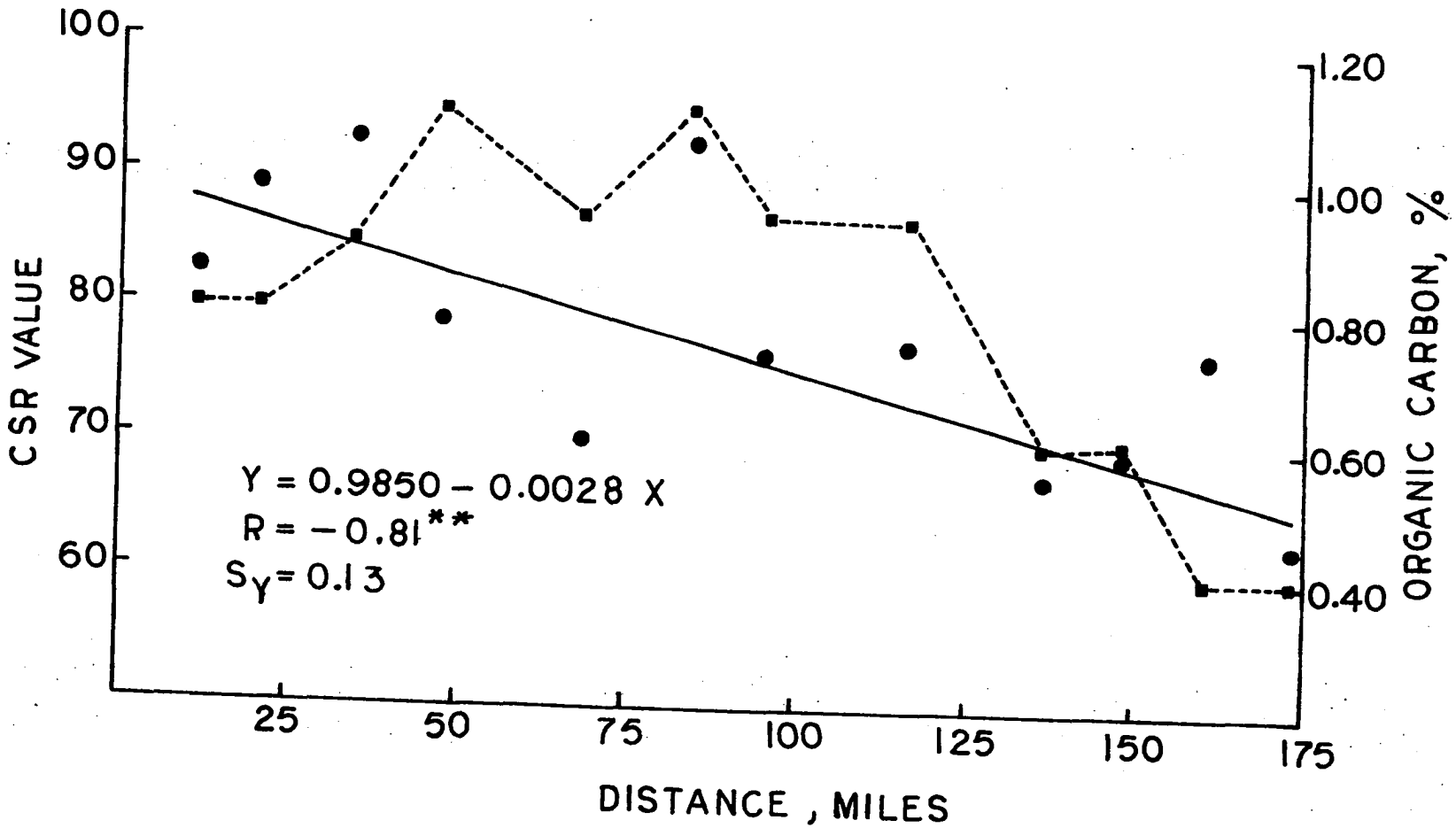
The carbon content of soils can be readily classified as either organic or inorganic. In this study, the inorganic carbon was considered to be essentially the calcium and magnesium carbonate which was reactive with hydrochloric acid and was evolved as carbon dioxide. All other carbon was determined by the Leco 70-second automatic analyzer method and was considered as organic and as such associated with vegetation.

Table 3 summarizes the organic carbon distribution data given in Appendix F for the various field sites. The average percent organic carbon was calculated for the total depth of material, tabulated in column 2 of Table 3, which contained detectable amounts. This data is shown in Figure 8. The distribution is adequately described by the regression equation $Y = 0.9850 - 0.0028X$ where Y is the average percent

Table 3. Summary of organic carbon distribution

Site	O.C. in Surface %	Depth of O.C. in.	Ave. O.C. %	Loess containing O.C., %
2	1.79	36	0.85	5.94
3	2.90	61	0.98	11.34
4	2.06	55	1.05	15.58
5	2.26	78	0.78	27.66
6	2.34	59	0.60	29.95
7	2.70	60	1.15	36.36
8	1.77	49	0.73	31.01
9	2.40	46	0.75	32.39
10	2.09	52	0.55	46.85
11	1.98	27	0.59	27.00
12	1.59	38	0.74	40.86
13	1.39	49	0.45	63.64

Figure 8. Relationship between corn suitability rating (CSR), percent organic carbon in the loess and distance from the loess source area. CSR is represented by the solid squares connected by the dashed line and organic carbon by the closed circles and the regression lire and equation


100
90
80
70
60
CSR VALUE
1.20
1.00
0.80
0.60
0.40
ORGANIC CARBON, %
Y = 0.9850 – 0.0028 X
R = –0.81**
SY = 0.13
25
50
75
100
125
150
175
DISTANCE , MILES

organic carbon and X is the distance from the loess source area. This equation, statistically significant at the one percent level, explains 65 percent of the variability of the data. This data fit demonstrates that the organic carbon content of the soils formed on the level divide summits decreases away from the loess source area. Close examination of the data, however, reveals more subtle changes. The organic carbon content of the soils near the Missouri River Valley is low. It appears to reach a maximum value at a distance of 35 miles and then exhibits a general decline with distance. The notable exception is site number 7, 84.4 miles away from the source area. The soil series is Macksburg and this site was observed to be somewhat depressional. Apparently this, or some other local factor, influenced the accumulation of organic carbon at that site to such a degree that it falls far outside the standard error of the equation, 0.13 percent.

The capacity of the soil to produce organic matter is reflected in its fertility level and moisture status. It is known that, in southwestern Iowa, the amount of acid soluble, or available, phosphorous decreases southeastward away from the Missouri River Valley (Godfrey and Riecken, 1957). With increasing soil development then, the amount of phosphorous available for plant growth decreases. The phosphorous has been converted from the calcium form to very insoluble iron,

aluminum and adsorbed forms.

Another, and more general indicator of soil fertility is the corn suitability rating (hereafter abbreviated CSR). CSR values reflect the capacity of the soil to produce a crop, in this case corn, and could be expected to reflect the general fertility level of the soil in addition to any other factors which might influence organic matter production. A CSR of 100 is the maximum value attainable by a soil and all others are evaluated against it. The CSR values of each site are plotted in Figure 8. Whereas available phosphorous decreased steadily with distance indicating a general decrease in fertility levels, the CSR values follow the same subtle trend as does the organic carbon content. Obviously then, there must be some other confounding factors involved. One of these could be moisture available for plant growth.

As mentioned during the discussion of the hydrologic data, the water-table occurs at considerable depth where the loess is thick. It seems unlikely that any capillary rise effects could bring water to the surface and also unlikely that the native plants could root deeply enough to tap the perched water-table for moisture. Reasonably then, although fertility levels appear quite high on the western end of the traverse, moisture could be a factor limiting organic matter production. Where CSR values are highest, optimum moisture conditions might be expected. Fertility levels would still

be adequate for considerable organic matter production. Further to the east along the traverse, fertility levels are much lower as are CSR values. Correspondingly, the organic carbon content of the soils is also the lowest. The perched water-table is very close to the surface and the moisture holding capacity of the soils is very high as reflected by the large volume of capillary pore spaces (Ulrich, 1949). It could be expected that moisture would be restrictive in this situation. However, the restriction on the east end of the traverse would be due to excess water and limited aeration where it would be a deficiency of moisture which would limit organic matter production on the west end.

The production of organic matter is only part of the system. It must then accumulate. As with the production of organic matter, its accumulation can be associated with several soil factors. One of these is soil moisture. With respect to organic carbon accumulation, the role of moisture is closely related to biological decomposition (Alexander, 1961). However, water is also an important factor in removal of organic matter by erosion. On the western end of the traverse, oxidative decomposition of organic matter is essentially unrestricted and, even though production capabilities are relatively high, accumulation is minimal. This is compounded by high runoff rates of water and removal of organic matter by erosion. Where more organic matter is produced, it

also accumulates without erosional losses. This is evidenced by the increase in organic carbon content of these soils as seen in Figure 8. On the eastern end of the traverse, accumulation would be greatest but production would be the limiting factor.

On the western end of the traverse, production of organic matter is limited by moisture deficiency even though fertility levels are high. Organic carbon does not accumulate at a great rate due to uninhibited biological decomposition and losses by erosion. The middle portion of the traverse has high enough fertility levels and adequate moisture to produce considerable organic matter and it in turn accumulates since the summits are flat enough to eliminate severe erosional losses. On the eastern end of the traverse, fertility levels are lowest and excess moisture is restrictive. Although accumulation could be great, production is low enough to be limiting.

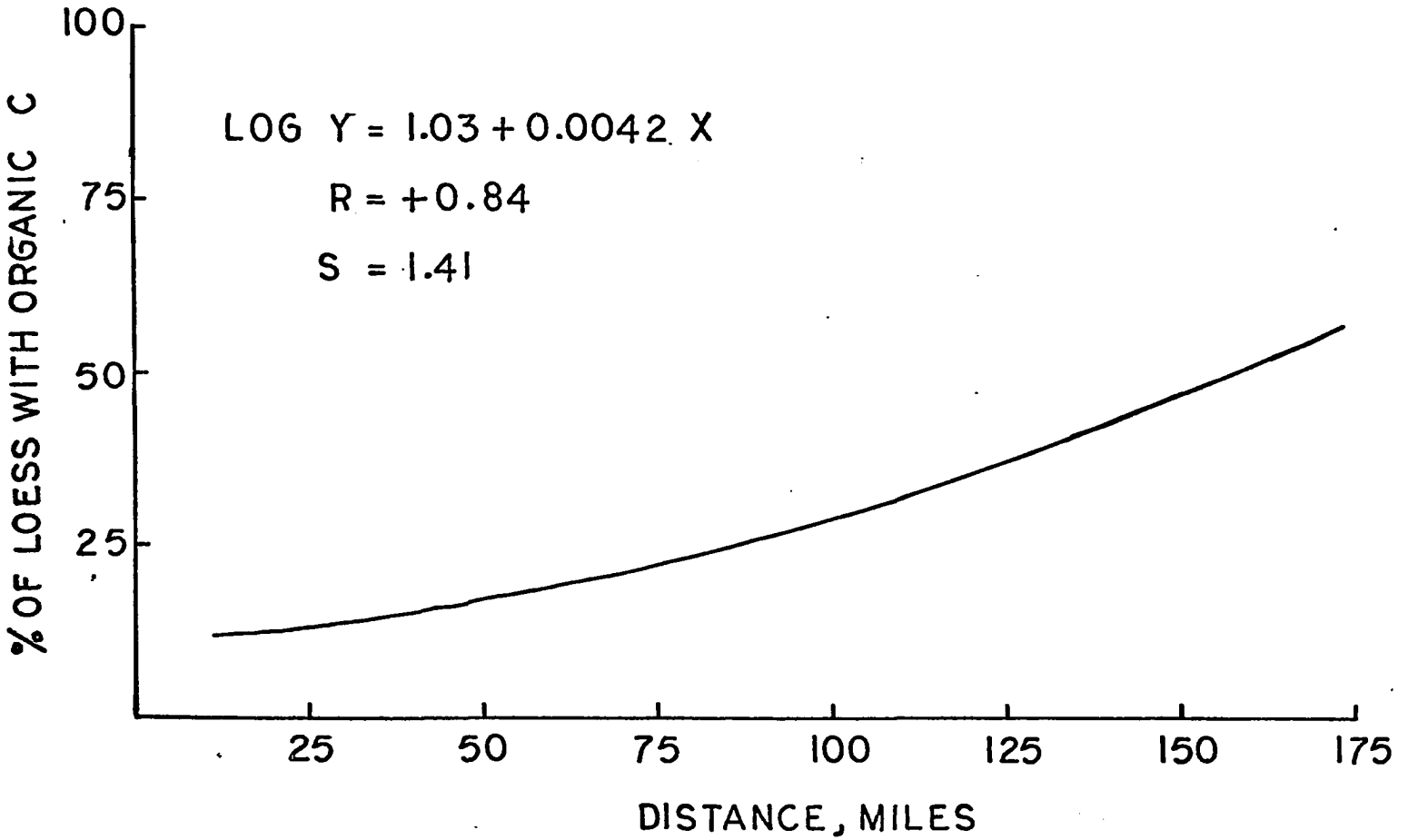
The amount of organic carbon present in a soil can be indicative of its degree of development but this is not accurate in the case of the loess derived soils of southwestern Iowa. It would, in fact, give an erroneous picture in this case. The depth to which the organic carbon has accumulated follows the same trend as the actual content. However, if the percent of the loess containing detectable organic carbon is regressed against distance from the source area, a

logarithmic relationship evolves as seen in Figure 9. From west to east along the traverse, the percent of the loess containing organic carbon increases. The correlation coefficient of 0.84 is significant at the one percent level and the equation explains 70 percent of the variability of the data. The indication is that there has been considerable alteration of the loess where it is thin and very little of it remains in an unaltered condition. In fact, the organic carbon extends deeply enough into the loess to overlap the present perched water-table at distances of 95.5 miles and greater from the source area. It would be reasonable then to state that at loess thicknesses of less than 150 inches, it would be unlikely that any unaltered loess would be encountered.

The presence or absence of inorganic carbon, as defined in this investigation as calcium and magnesium carbonate, can also be used as an indicator of alteration of parent material. In addition, the quantity of inorganic carbon present, reported as percent calcium carbonate equivalent, can also be used. Smith (1942) utilized calcium carbonate equivalent data in arriving at his effective age concept. In the absence of radiocarbon dating techniques, leaching was used as a measure of time and alteration.

It was observed in this study that the depth to carbonates was not a function of distance but rather appeared to be randomly displaced points about a straight line. Beyond a

Figure 9. Relationship between percent of the loess containing detectable organic carbon and distance from the loess source area


LOG Y = 1.03 + 0.0042 X
R = +0.84
S = 1.41
% OF LOESS WITH ORGANIC C
100
75
50
25
25
50
75
100
125
150
175
DISTANCE, MILES

distance of 84.4 miles from the source area, no carbonates were detected. Within that portion of the loess province where carbonates were detected, several systematic relationships were defined.

Since depth of leaching was not functionally related to distance, the percent of loess containing carbonates was checked. Figure 10 shows the results of this. The percent of loess which was found to be calcareous decreased with distance from the source area. The correlation coefficient of 0.98 was significant at the one percent level and the equation explained 96 percent of the variability of the data.

Within the unleached zone, the calcium carbonate equivalent was found to be very systematically related to distance (Figure 11). The second degree polynomial equation which described the data points explained 92 percent of the variability of the data. Within the calcareous zone at any particular site, the calcium carbonate content showed very little variability (Appendix F). Since the data appeared so uniform and inorganic carbon was very well correlated with distance, it seemed reasonable to assume that it represented parent material essentially unaltered since deposition. If this were true, the calcium carbonate equivalent of the loess could be extrapolated eastward along the traverse beyond 84.4 miles and the original carbonate content estimated. It has been reported that the loess, even 175 miles from the source area

Figure 10. Relationship between percent of the loess containing calcium carbonate and distance from the loess source area

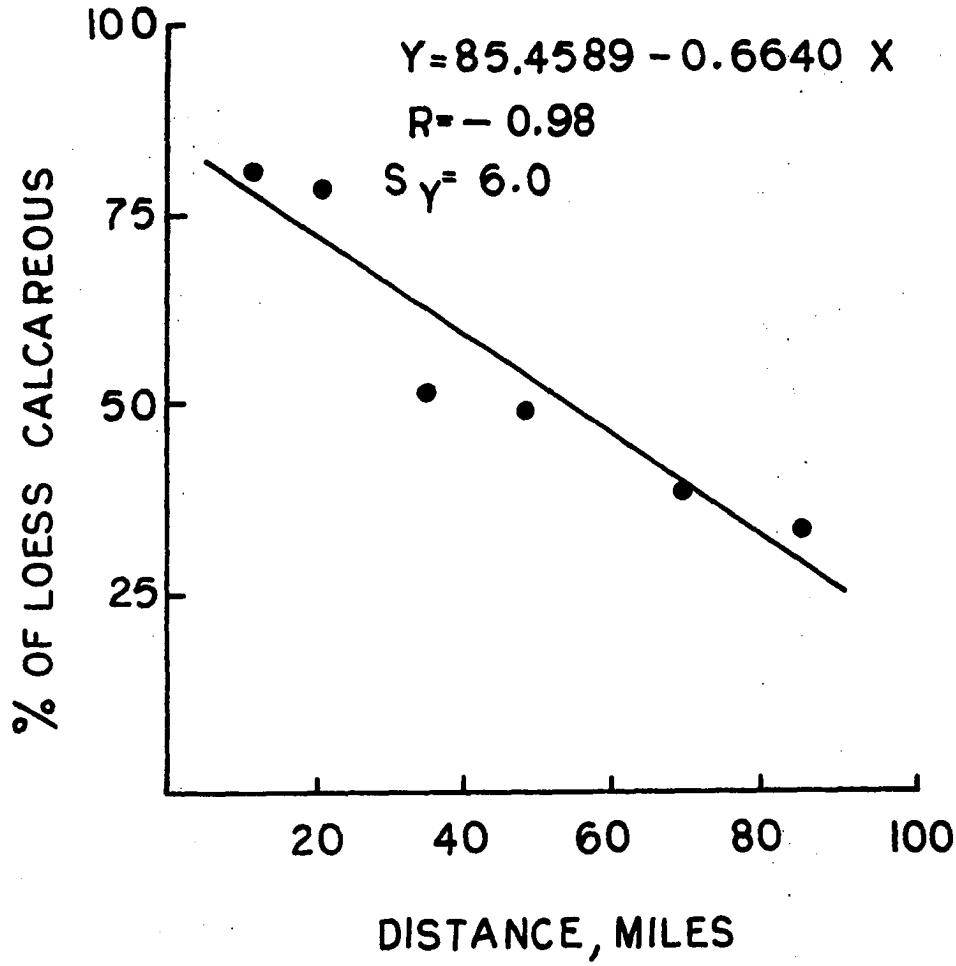
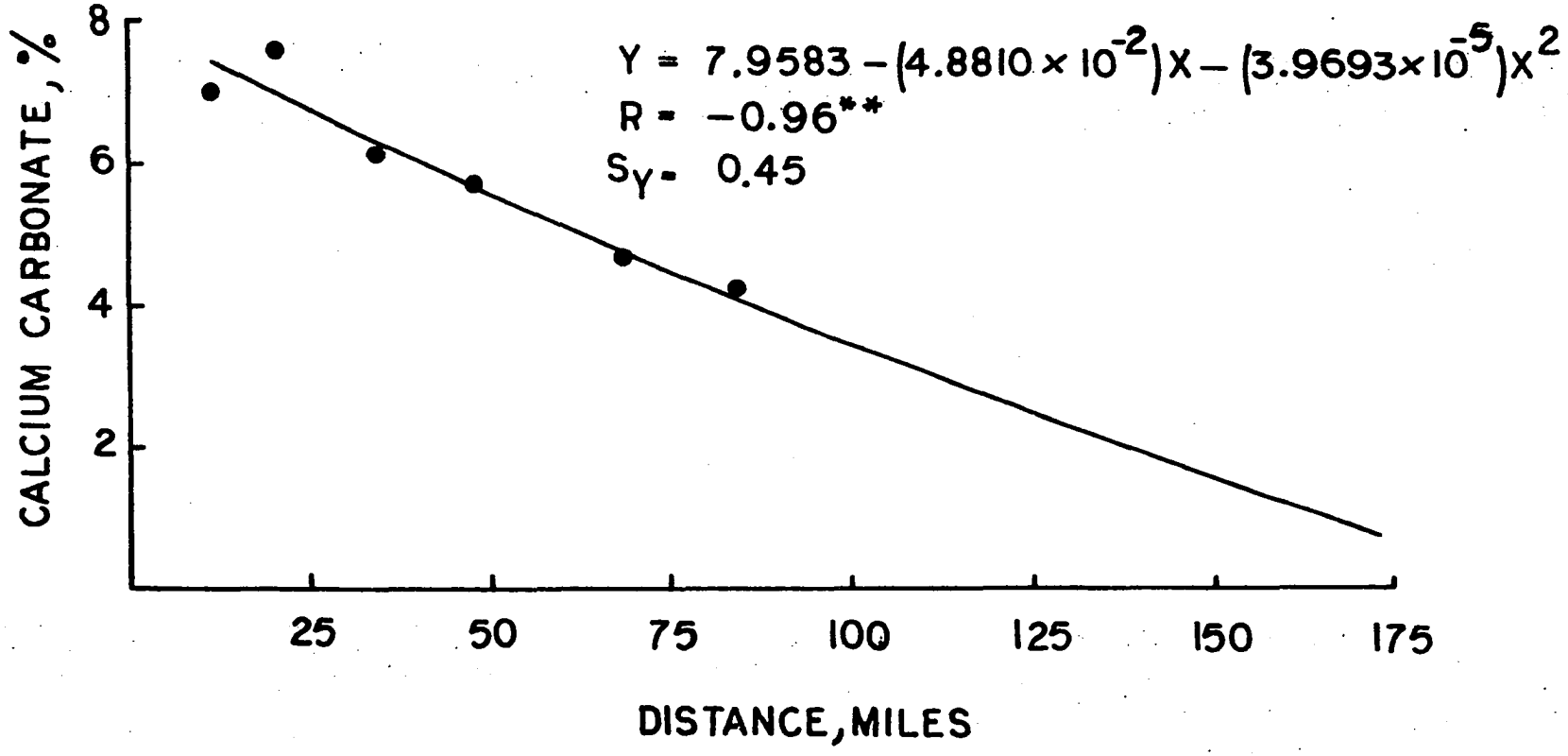

Y=85.4589 - 0.6640 X
R= - 0.98
S_Y= 6.0
100
75
50
25
% OF LOESS CALCAREOUS
20
40
60
80
100
DISTANCE, MILES

Figure 11. Relationship between percent calcium carbonate equivalent of the loess and distance from the loess source area


CALCIUM CARBONATE, %
8
6
4
2
25
50
75
100
125
150
175
DISTANCE, MILES
Y = 7.9583 − (4.8810 × 10⁻²)X − (3.9693 × 10⁻⁵)X²
R = −0.96**
Sy = 0.45

was at one time calcareous (Ruhe, 1969b). The percent calcium carbonate equivalent then varied systematically from 7.96 near the source area to 4.12 percent 84.4 miles from the source area. It is predicted to have been approximately 0.69 percent 173.2 miles from the source area at the time of original deposition.

With calcium carbonates at such a low initial level, it would require less leaching to remove it completely. In addition to the low initial carbonate content, the high water-table on the eastern end of the traverse would be a definate factor contributing to leaching removal of carbonate minerals. Once the carbonates have been removed and the pH subsequently lowered, weathering would be expected to occur at an increased rate (Glen et al., 1960). Therefore, part of the explanation of increasing degree of soil development along the traverse could be rapid removal of low amounts of initial carbonate minerals and subsequent acceleration of clay translocation and formation.

Particle size distribution and trends

An earlier investigation in northeast Kansas (Hanna and Bidwell, 1955) concluded that the parent material in that loess province became progressively finer textured with distance away from the source area. No such attempt has been made in southwestern Iowa. It may be logically assumed from

the distributional pattern of calcareous loess that it represents the condition of the original loess at the time of deposition. From this data, the calcium carbonate equivalent has been predicted and appears reasonable. If this is the case, as it appears to be, then prediction of original parent material particle size distribution may be approximated.

If the calcareous loess is essentially unweathered, then throughout the calcareous zone at any site there should be very little variance from the mean percent of any one size fraction. This statistical data is presented in Table 4. In addition, the calculated mean percent and coefficient of variability is included. In all size fractions, the standard deviation from the mean is low. Since loess may be considered a sediment, some deviation is expected. The sand fraction was found to be composed of varying amounts of secondary iron-manganese concretions obviously not a sedimentologic factor. These will be delt with later as part of a different loess characteristic. The standard deviation of the various size fractions in the calcareous loess should be smaller than those for either the leached surface zone, including the soil solum, or the entire thickness of loess including both the leached and unleached zones. This data is presented in Table 5. A comparison of Tables 4 and 5 shows that relatively little alteration of particle sizes has occurred in the unleached zone. The large standard deviations observed in

Table 4. Mean, standard deviation and coefficient of variation of calcareous loess particle size analysis

Site	Stat.[1]	> 62	31-62	16-31	8-16	4-8	2-4	1-2	0.5-1	< 0.5
2	1	0.93	25.28	34.62	13.15	5.14	3.43	3.37	10.38	3.59
2	2	0.13	2.52	2.10	1.28	0.56	0.48	0.61	2.21	1.20
2	3	13.97	9.96	6.06	9.73	10.89	13.99	18.10	21.29	33.42
3	1	1.07	25.52	33.52	13.26	4.75	3.76	3.49	9.72	5.10
3	2	0.02	1.91	2.21	1.02	0.48	0.47	0.56	1.39	0.45
3	3	57.94	7.48	6.59	7.69	10.10	12.50	16.04	14.30	8.82
4	1	0.94	24.47	32.59	13.64	5.64	3.90	4.05	9.01	5.98
4	2	0.35	2.13	1.16	1.28	1.08	0.90	0.47	0.94	0.89
4	3	37.23	8.81	3.55	9.38	19.14	23.07	11.60	10.43	14.88
5	1	1.06	20.18	32.54	15.42	6.77	4.88	4.73	9.87	4.62
5	2	0.55	1.42	1.54	1.13	0.71	0.63	0.53	0.86	0.88
5	3	51.88	7.03	4.73	7.32	10.48	12.90	11.20	8.71	19.04
6	1	0.90	15.39	31.99	17.82	7.27	4.76	4.60	10.96	6.81
6	2	0.17	1.76	1.17	1.15	0.68	0.45	0.37	0.71	1.17
6	3	18.88	11.43	3.65	6.45	9.35	9.45	8.04	6.78	17.18
7	1	1.17	16.06	31.58	17.50	7.53	4.42	4.41	10.15	7.04
7	2	0.24	2.25	1.09	1.30	0.85	0.47	0.63	0.79	0.73
7	3	20.51	14.00	3.45	7.42	11.28	10.63	13.74	7.78	10.36

[1] 1 is calculated mean value in microns
2 is standard deviation from mean
3 is coefficient of variation in percent

Table 5. Standard deviation of various particle size fractions in leached loess and total loess thickness where calcareous loess was present

Site	Sample[1]	> 62	31-62	16-31	8-16	4-8	2-4	1-2	0.5-1	< 0.5
2	1	0.30	2.20	2.58	0.92	0.40	0.42	0.65	1.16	2.58
2	2	0.40	2.59	2.76	1.24	0.60	0.46	0.60	2.91	2.11
3	1	0.10	2.53	2.49	1.64	1.14	0.96	0.56	1.15	1.73
3	2	0.55	3.08	3.25	2.37	0.78	0.70	0.73	1.61	2.84
4	1	0.20	2.64	1.89	1.16	0.77	0.74	0.67	1.04	3.01
4	2	0.35	3.28	2.79	1.78	1.05	0.89	0.67	1.26	2.77
5	1	0.20	1.81	2.69	0.92	0.41	0.40	1.11	1.88	3.63
5	2	0.50	2.29	2.97	1.80	0.73	0.66	0.82	1.81	3.27
6	1	0.10	1.74	2.40	1.85	0.62	0.41	0.55	1.60	3.78
6	2	0.35	1.97	3.40	1.59	0.77	0.42	0.49	1.61	3.76
7	1	0.32	1.30	3.12	1.14	0.72	0.60	0.67	1.14	4.16
7	2	0.37	2.33	3.65	1.95	0.98	0.64	0.31	1.34	4.70

[1] Sample 1 is leached loess
Sample 2 is total loess thickness

the 16 - 31 and 8 - 16 micron fractions indicates these to be actively altered. The 4 - 8, 2 - 4 and 1 - 2 micron fractions show small standard deviations while the 0.5 - 1 and < 0.5 micron fractions showed the greatest modification. The larger standard deviations for the leached surface zones, including the soil sclum, lend credulance to the assumption of the greatest degree of weathering in the leached loess and relatively little alteration in the unleached portion.

On the basis of this interpretation, the calcareous loess can be taken as representative of the original loess parent material. Since the calcareous loess extended only 84.4 miles from the source area, only the sites within this reach could be utilized for prediction of parent material. Each of the nine size fractions at each site was regressed against distance from the source area to establish the functional relationships existing within the calcareous loess. The predicted parent material relationships are shown in Figures 12 through 20. The prediction equations used to calculate the particle size composition of loess parent material are shown in the appropriate figures. As a check on the accuracy of these predictions, the measured percentage of each fraction was checked against the predicted percentage (Table 6). Very close agreement can be seen between predicted and measured percentages.

Figure 12. Prediction model for > 62 micron diameter sand size fraction of loess parent material

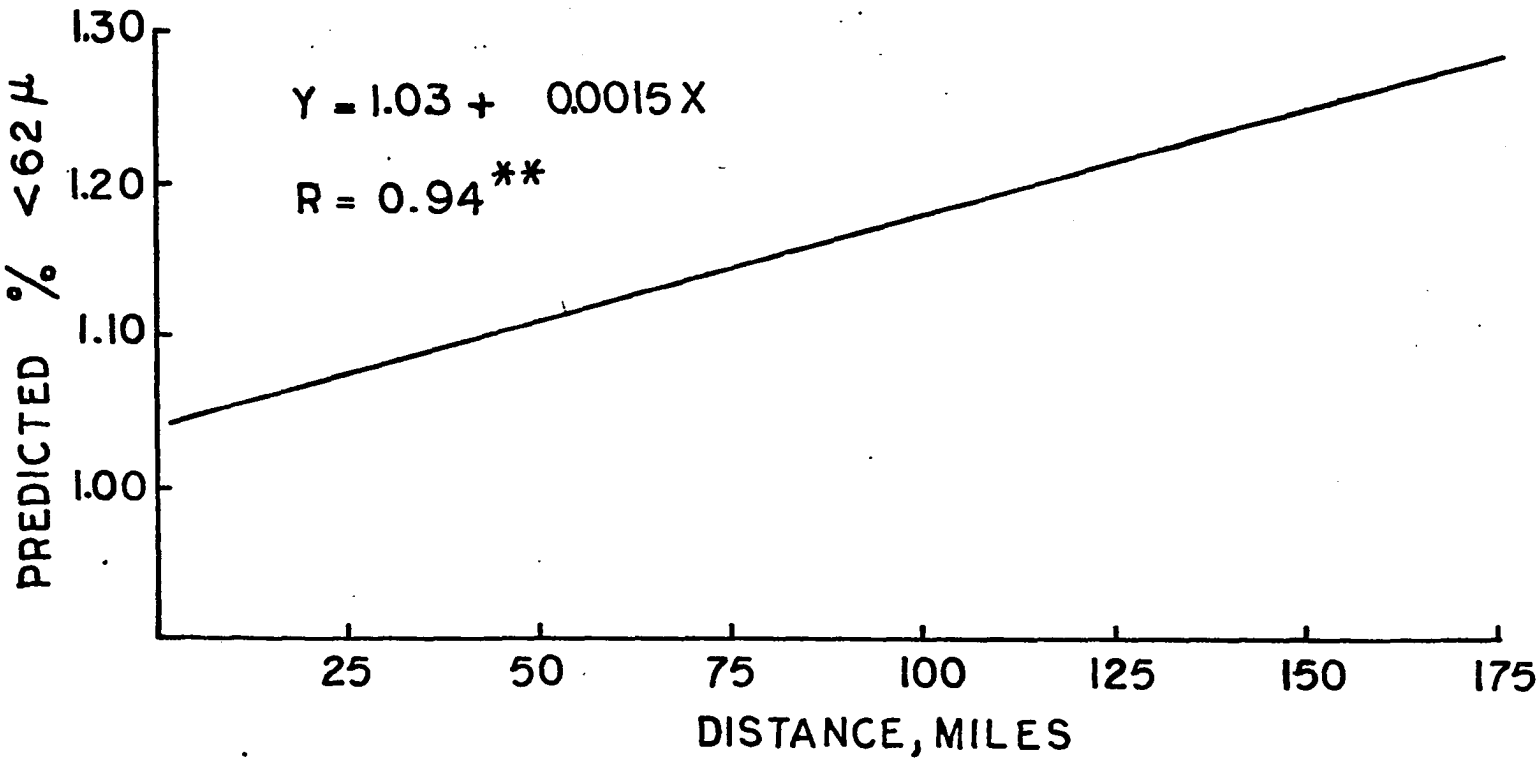

Y = 1.03 + 0.0015 X
R = 0.94**
PREDICTED % <62 μ
1.30
1.20
1.10
1.00
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 13. Prediction model for 31 to 62 micron very coarse silt size fraction of loess parent material

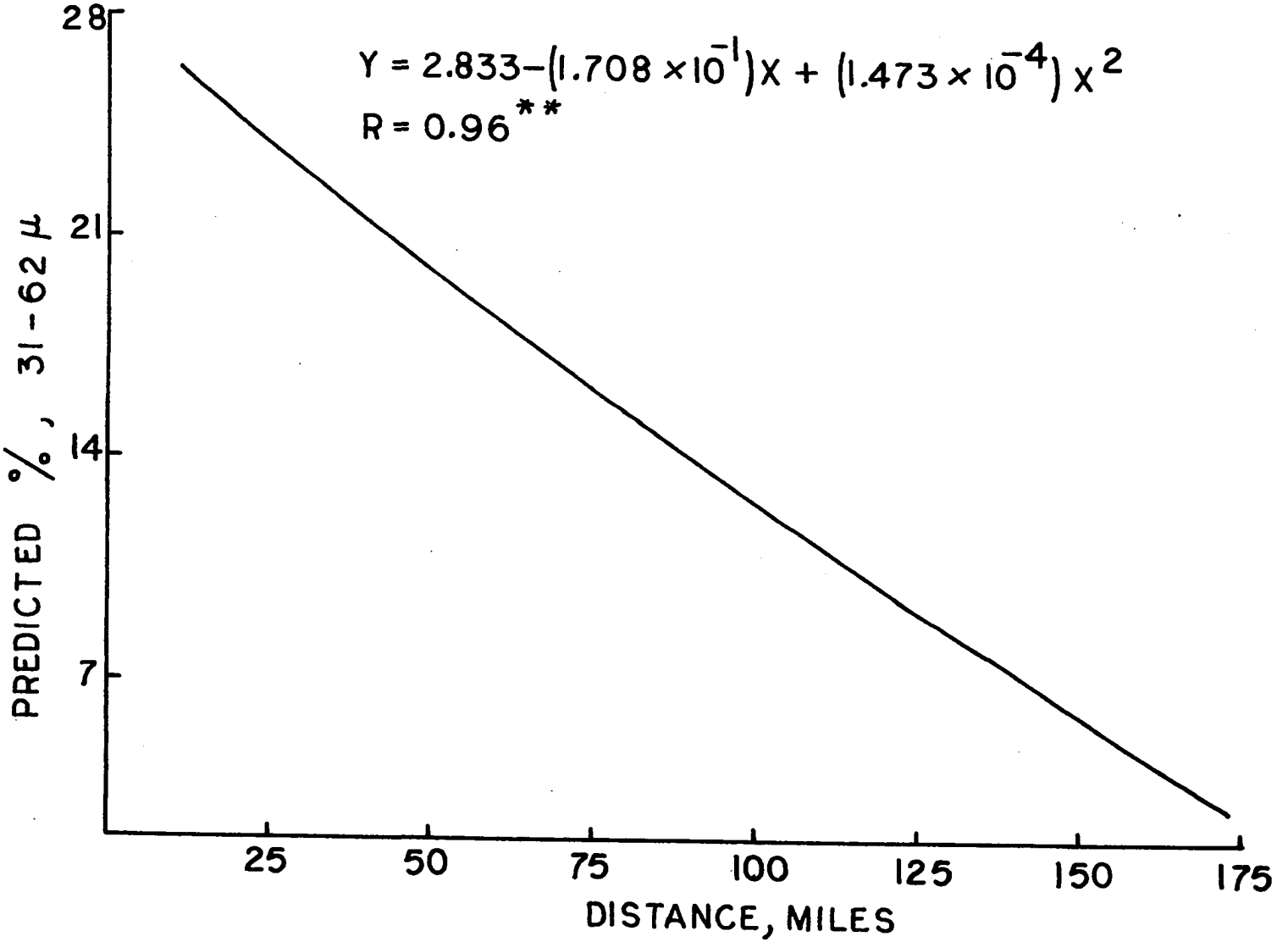

$Y = 2.833 - (1.708 \times 10^{-1})X + (1.473 \times 10^{-4})X^2$
$R = 0.96^{**}$
PREDICTED %, 31-62 μ
28
21
14
7
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 14. Prediction model for 16 to 31 micron coarse silt size fraction of loess parent material

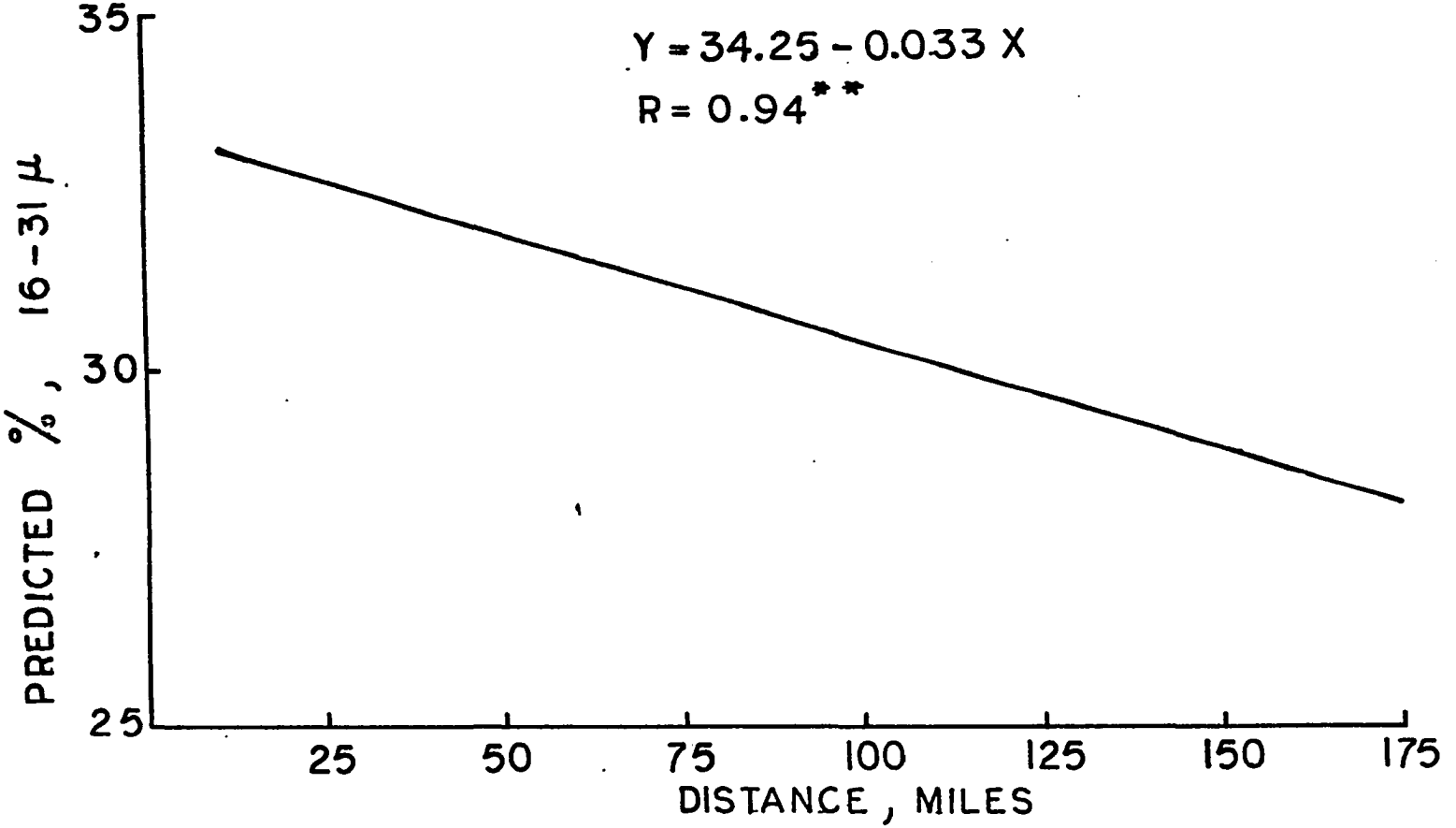

Y = 34.25 - 0.033 X
R = 0.94**
PREDICTED %, 16-31 μ
35
30
25
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 15. Prediction model for 8 to 16 micron medium silt size fraction of loess parent material

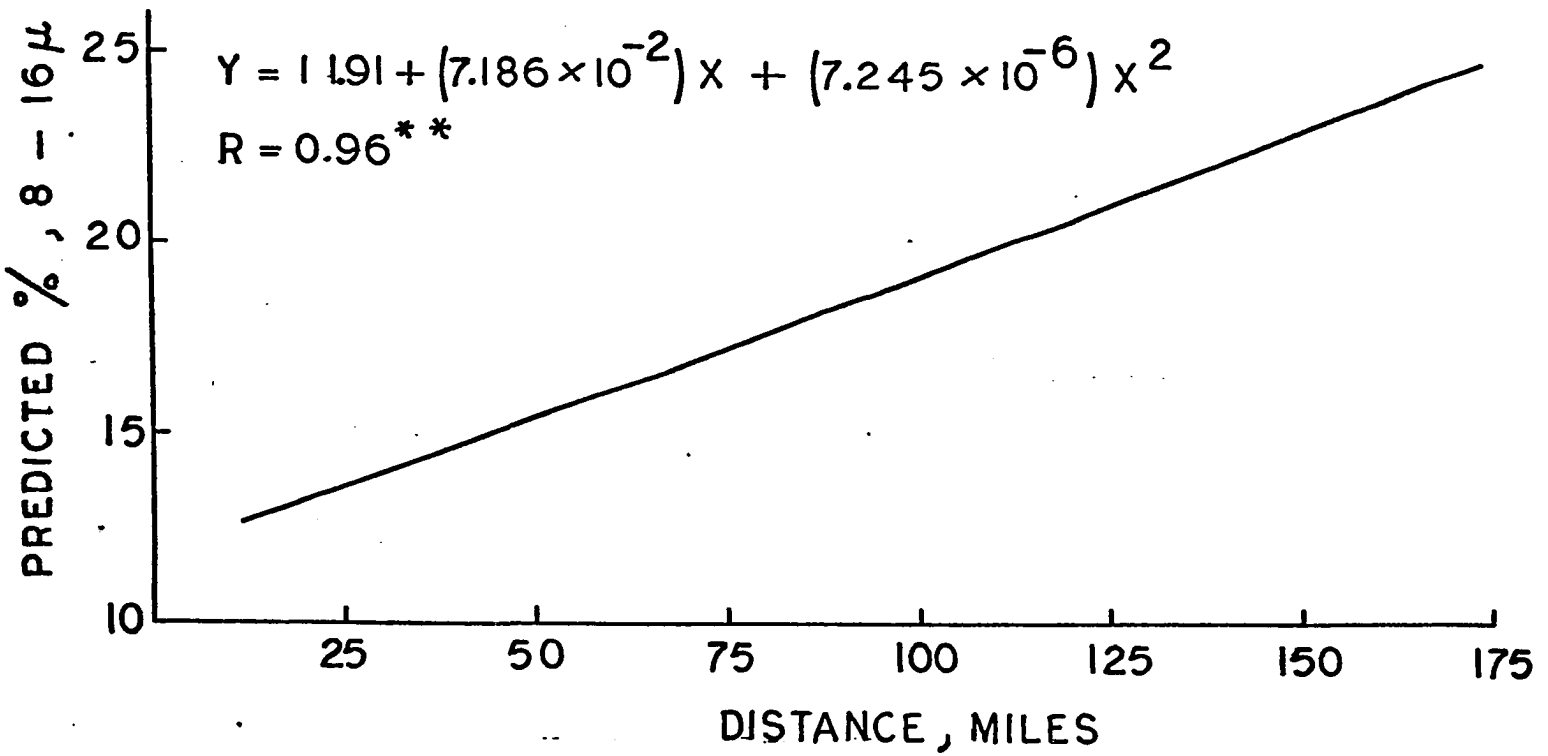

Y = 11.91 + (7.186 × 10^-2) X + (7.245 × 10^-6) X^2
R = 0.96**
PREDICTED %, 8 - 16 μ
25
20
15
10
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 16. Prediction model for 4 to 8 micron very fine silt size fraction of loess parent material

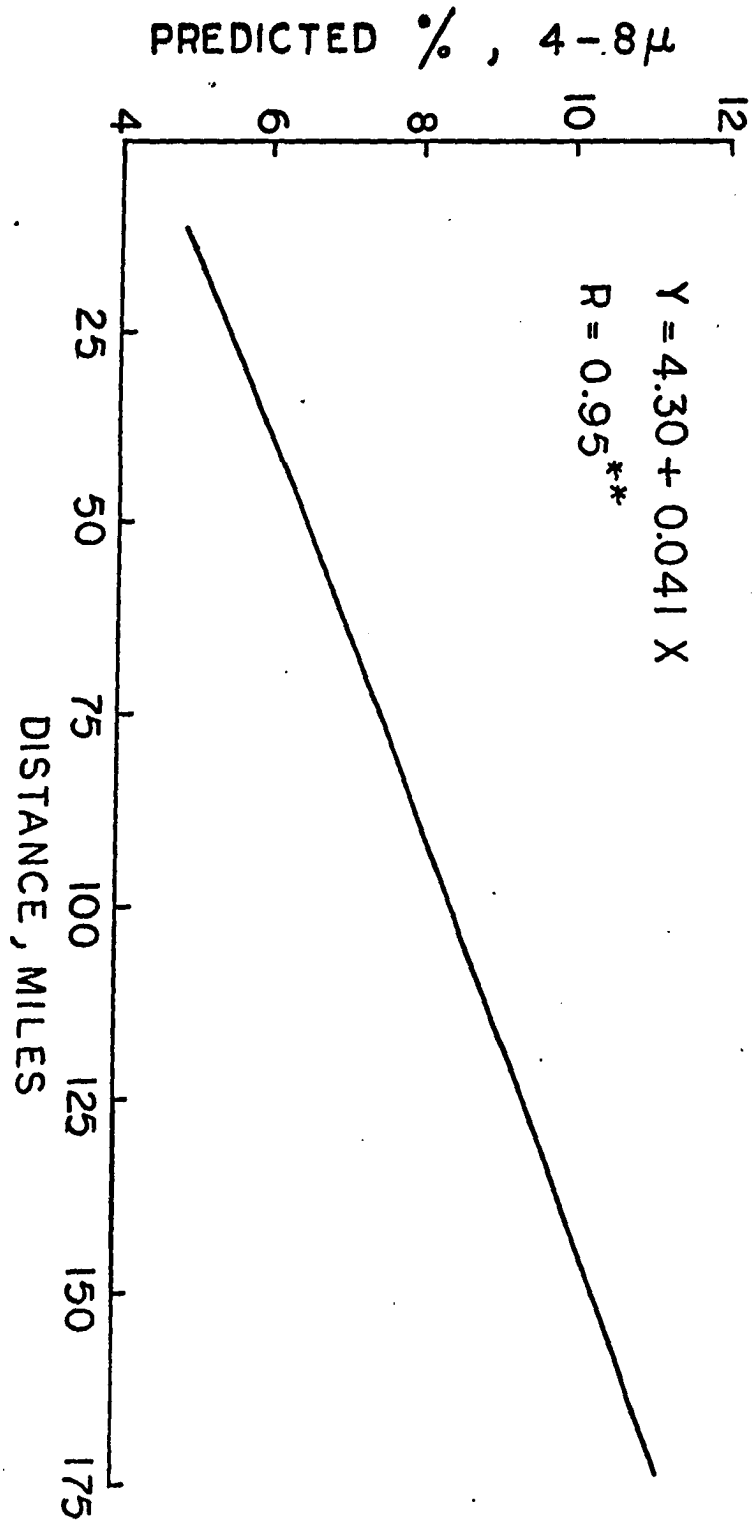

PREDICTED %, 4-8μ
4
6
8
10
12
25
50
75
100
125
150
175
DISTANCE, MILES
Y = 4.30 + 0.041 X
R = 0.95**

Figure 17. Prediction model for 2 to 4 micron very fine silt size fraction of loess parent material

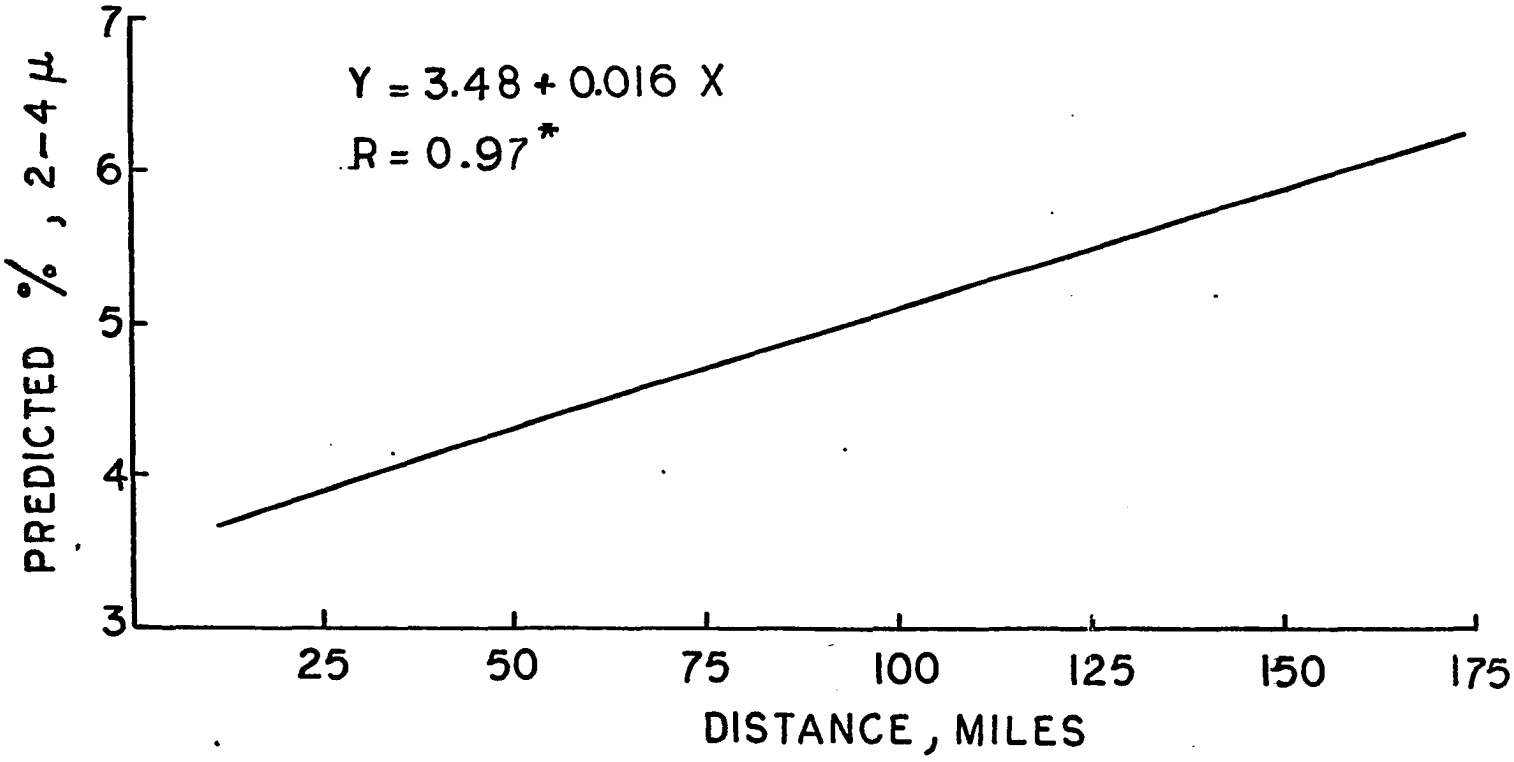

Y = 3.48 + 0.016 X
R = 0.97*
PREDICTED %, 2-4 μ
7
6
5
4
3
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 18. Prediction model for 1 to 2 micron coarse clay size fraction of loess parent material

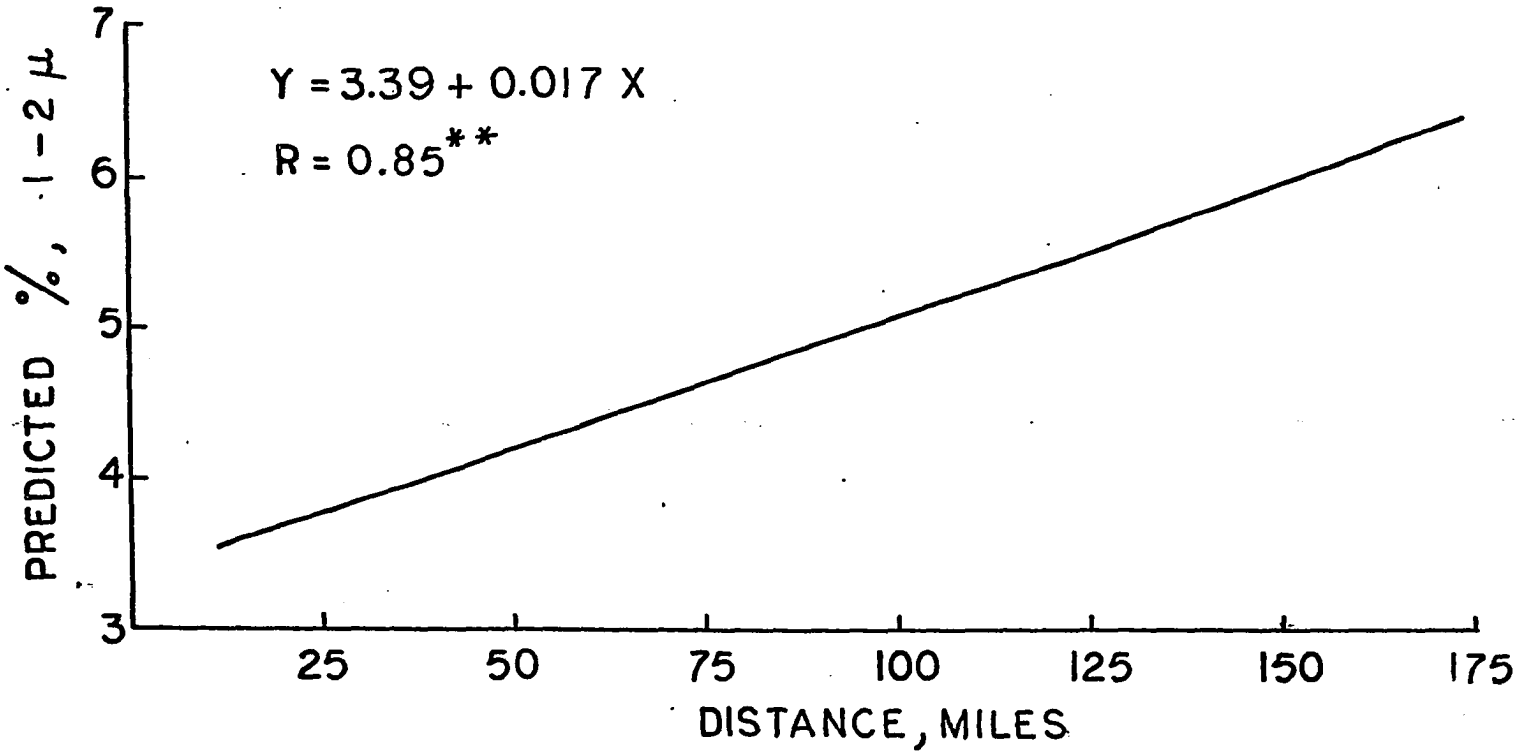

Y = 3.39 + 0.017 X
R = 0.85**
PREDICTED %, 1-2 μ
7
6
5
4
3
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 19. Prediction model for 0.5 tc 1 micron medium clay size fraction of lcess parent material.

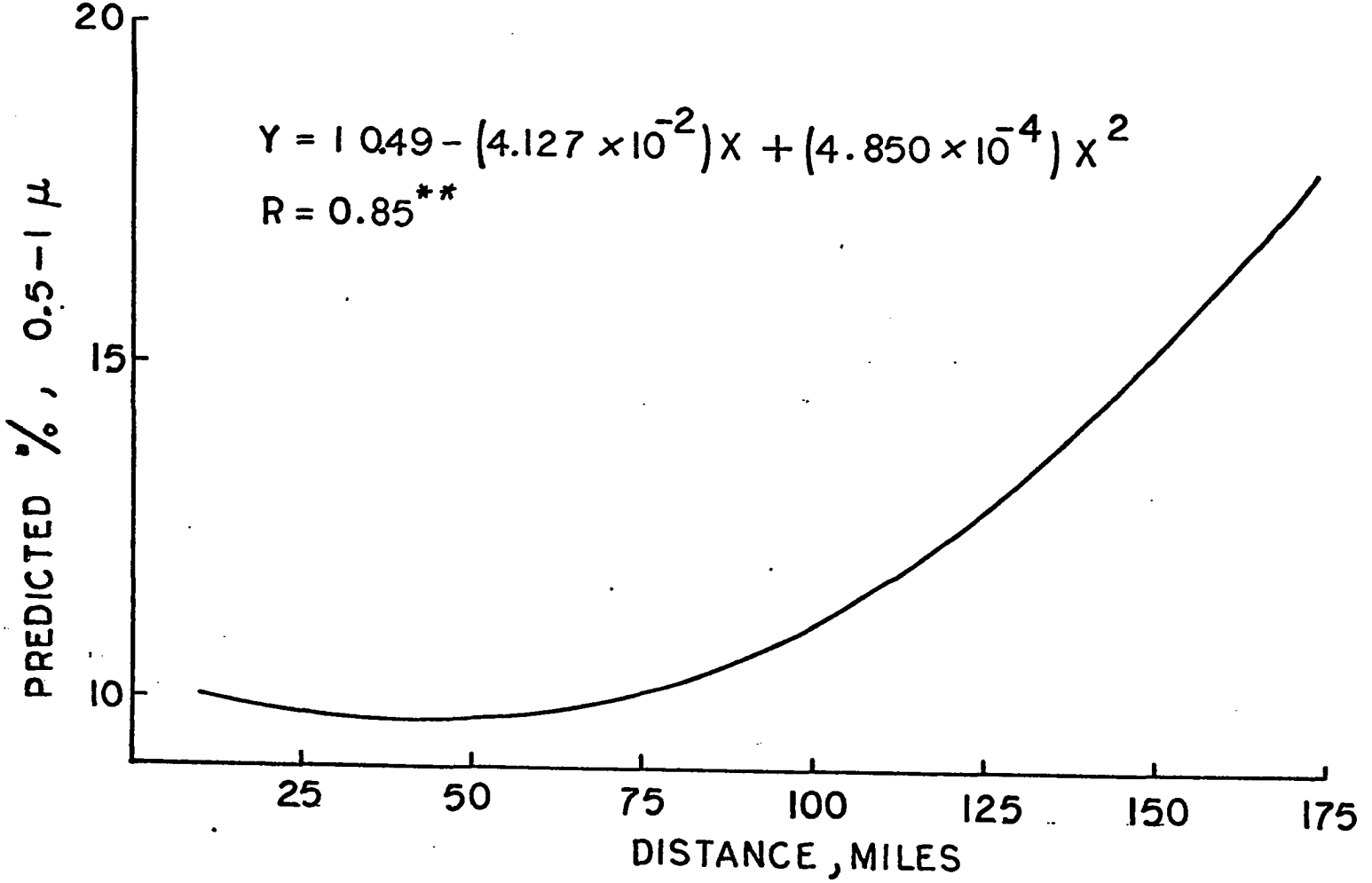

$Y = 1\,0.49 - (4.127 \times 10^{-2})X + (4.850 \times 10^{-4})X^2$
$R = 0.85^{**}$
PREDICTED %, 0.5–1 μ
20
15
10
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 20. Prediction model for < 0.5 micron fine clay size fraction of loess parent material

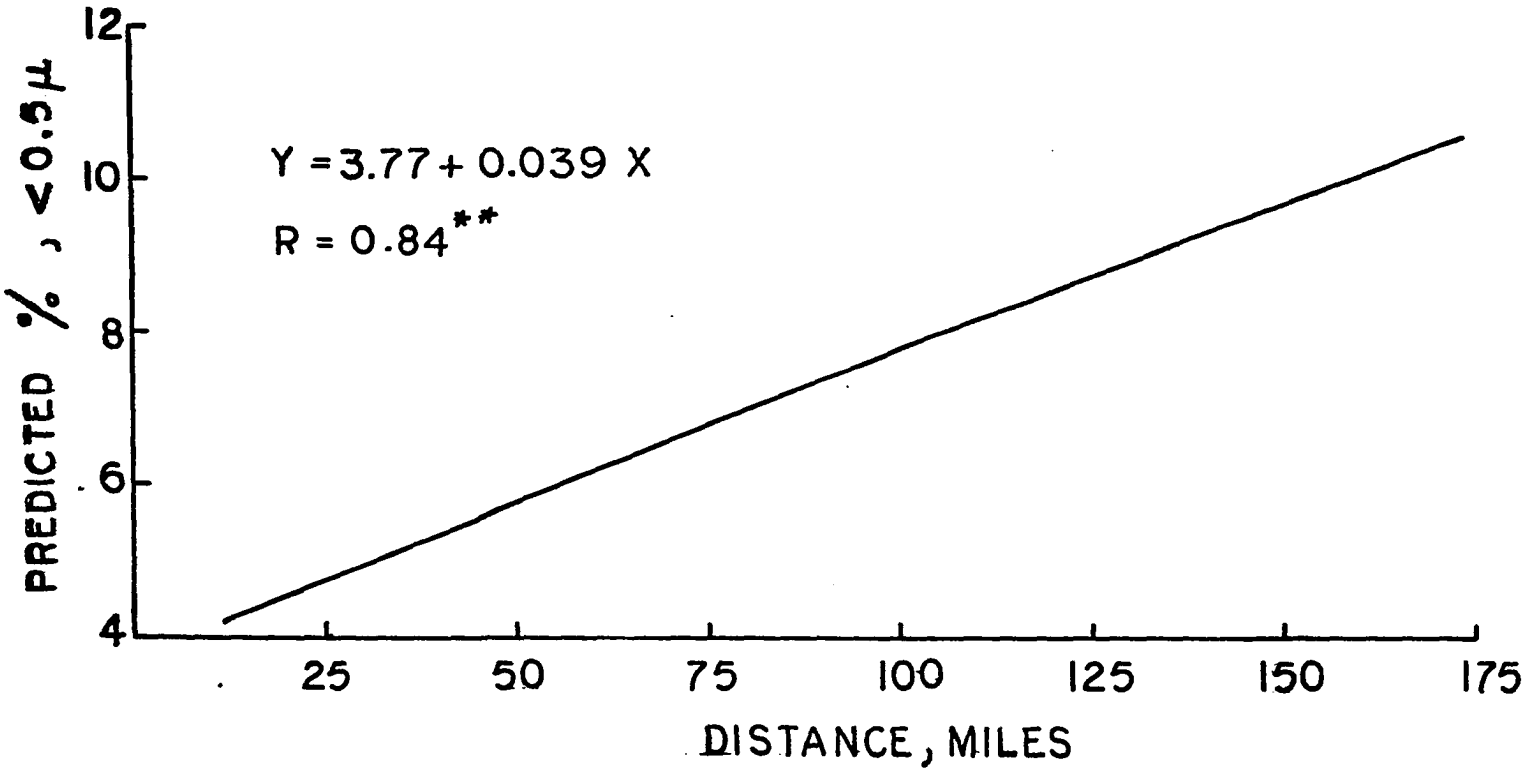

PREDICTED % , <0.5μ
12
10
8
6
4
Y = 3.77 + 0.039 X
R = 0.84**
25
50
75
100
125
150
175
DISTANCE, MILES

Table 6. Predicted percent of each size fraction and measured percent in calcareous loess

Site	Value[1]	> 62	31-62	16-31	8-16	4-8	2-4	1-2	0.5-1	< 0.5
2	1	0.96	26.35	34.02	12.75	4.87	3.66	3.54	10.08	4.20
2	2	0.93	25.28	34.62	13.15	5.14	3.43	3.37	10.38	3.59
3	1	0.98	24.86	33.68	13.34	5.23	3.81	3.70	9.84	4.56
3	2	1.07	25.52	33.52	13.26	4.75	3.76	3.49	9.72	5.10
4	1	0.99	22.58	33.16	14.41	5.79	4.03	3.95	9.64	5.13
4	2	0.94	24.17	32.59	13.64	5.64	3.90	4.05	9.01	5.98
5	1	1.01	20.50	32.68	15.36	6.32	4.24	4.18	9.63	5.66
5	2	1.06	20.18	32.54	15.42	6.77	4.88	4.73	9.87	4.62
6	1	1.04	17.34	31.93	16.86	7.13	4.58	4.55	9.94	6.48
6	2	0.90	15.39	31.99	17.82	7.27	4.76	4.60	10.46	6.81
7	1	1.06	14.96	31.37	18.02	7.76	4.83	4.83	10.46	7.12
7	2	1.17	16.06	31.58	17.50	7.53	4.42	4.51	10.51	7.04

[1] 1 is predicted percent
2 is measured percent

In light of this close agreement, the predictions were extended eastward along the traverse where no calcareous loess was found to exist. The entire set of predicted values is shown in Table 7. The > 62 micron sand fraction increases with distance. However, as will be shown later, this is not a sedimentologic feature of the loess but rather, a result of post-depcsitional formation of secondary iron and manganese concretions in the sand size fraction. The 31 - 62 and 16 - 31 micron fractions decrease with distance from the loess source area. Smith (1942), Hutton (1947) and Ulrich (1949) all agree with this, having their particle size break at 20 microns between increasing and decreasing particle size trends with distance. All other size fractions smaller than 16 microns increase with distance. In other words, except for secondary sand size concretions, the loess parent material is predicted to become much finer with distance away from the source area.

Figure 21 shows the change in the < 2 micron clay fraction in the zone of maximum clay accumulation and the predicted percent < 2 micron clay in the parent material against distance. The relationship between change from parent material and soil is graphed in Figure 22. This change is very systematic, indicating that some alteration has occurred in this size fraction. Figure 23 shows the regression of the change in the < 0.5 micron fraction from the predicted parent

Table 7. Predicted parent material composition at all field research sites along the traverse

Site	Dist.	> 62	31-62	16-31	8-16	4-8	2-4	1-2	0.5-1	< 0.5
2	11.7	0.96	26.35	34.02	12.75	4.87	3.66	3.54	10.08	4.20
3	20.7	0.98	24.86	33.68	13.34	5.23	3.81	3.70	9.84	4.56
4	34.7	0.99	22.58	33.16	14.41	5.79	4.03	3.95	9.64	5.13
5	47.8	1.01	20.50	32.68	15.36	6.32	4.24	4.18	9.63	5.66
6	68.4	1.04	17.34	31.93	16.86	7.13	4.58	4.55	9.94	6.48
7	84.4	1.06	14.96	31.37	18.02	7.76	4.83	4.83	10.46	7.12
8	95.5	1.08	13.36	30.98	18.84	8.19	5.01	5.02	10.97	7.56
9	116.2	1.11	10.47	30.28	20.35	8.99	5.34	5.38	12.24	8.37
10	136.7	1.14	7.73	29.59	21.86	9.78	5.66	5.74	13.91	9.16
11	148.5	1.16	6.21	29.21	22.74	10.23	5.85	5.95	15.06	9.62
12	160.5	1.18	4.71	28.82	23.63	10.68	6.04	6.16	16.36	10.08
13	173.2	1.20	3.17	28.41	24.57	11.16	6.24	6.38	17.89	10.56

Figure 21. Relationships between measured < 2.0 micron clay size fraction in the B2 horizon of maximum accumulation, predicted < 2.0 micron clay in the loess parent material and distance from the loess source area

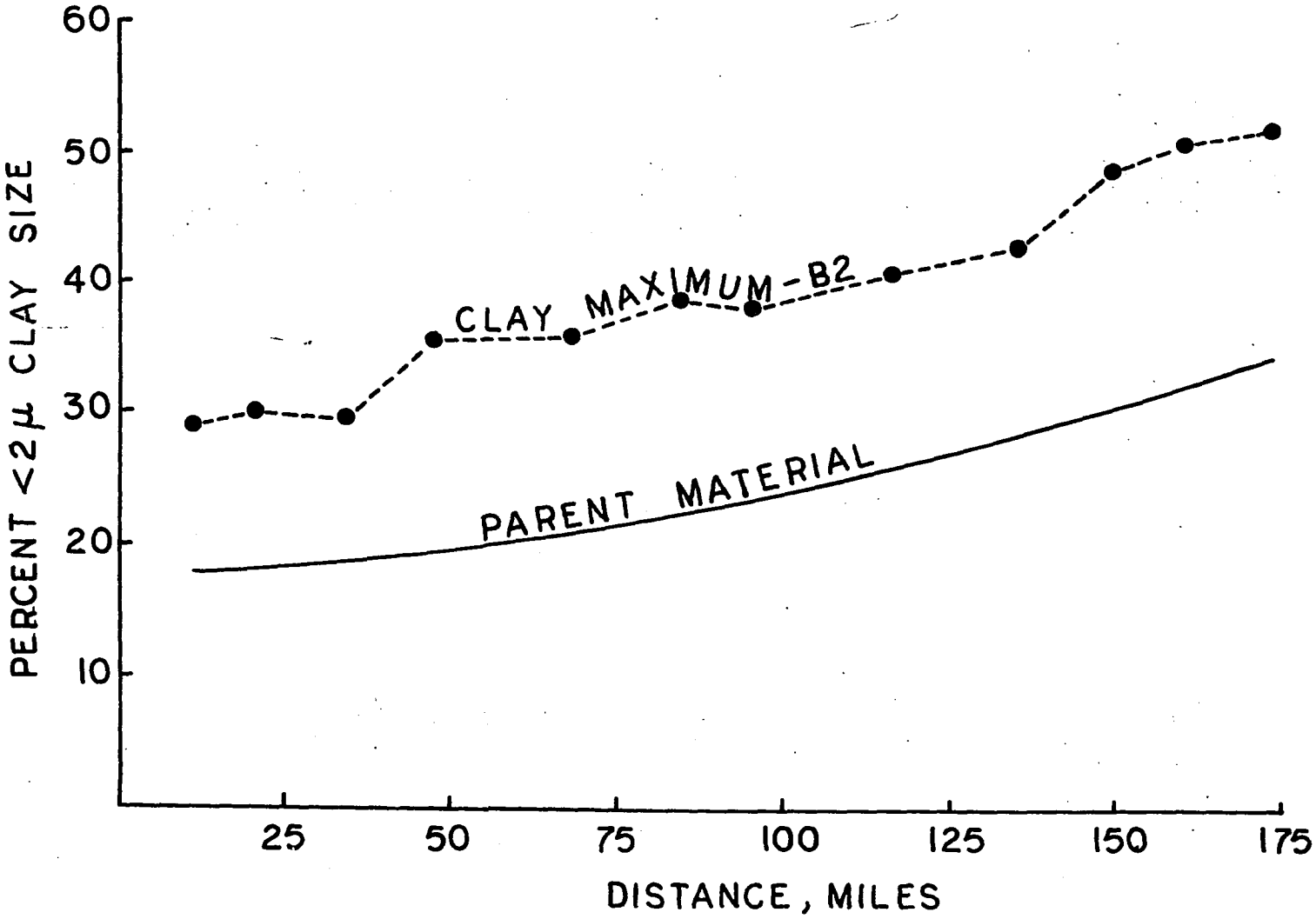

60
50
40
30
20
10
PERCENT <2μ CLAY SIZE
CLAY MAXIMUM - B2
PARENT MATERIAL
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 22. Relationship between the increase in < 2.0 micron clay size fraction in B2 horizon of maximum accumulation and distance from the loess source area

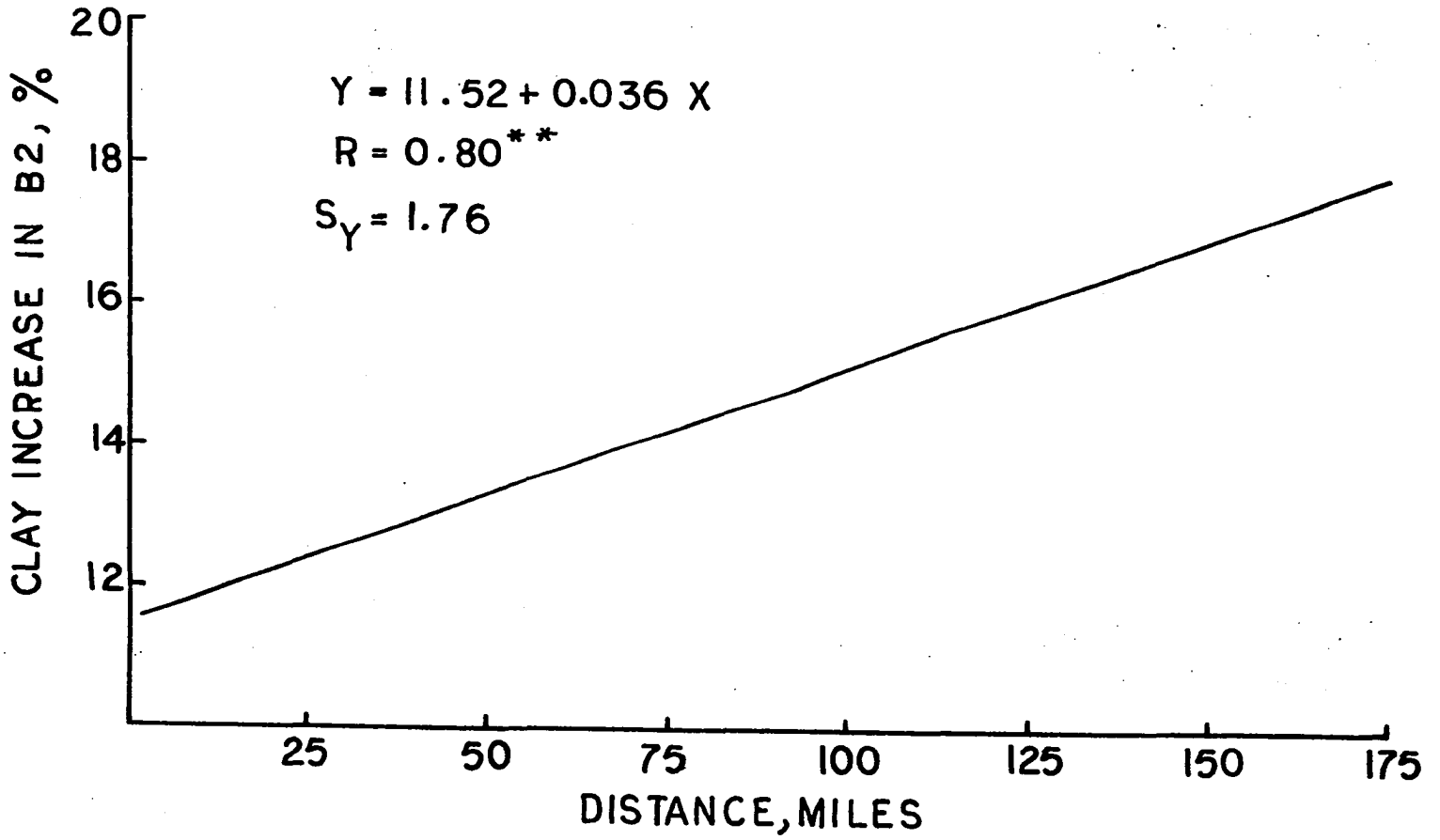
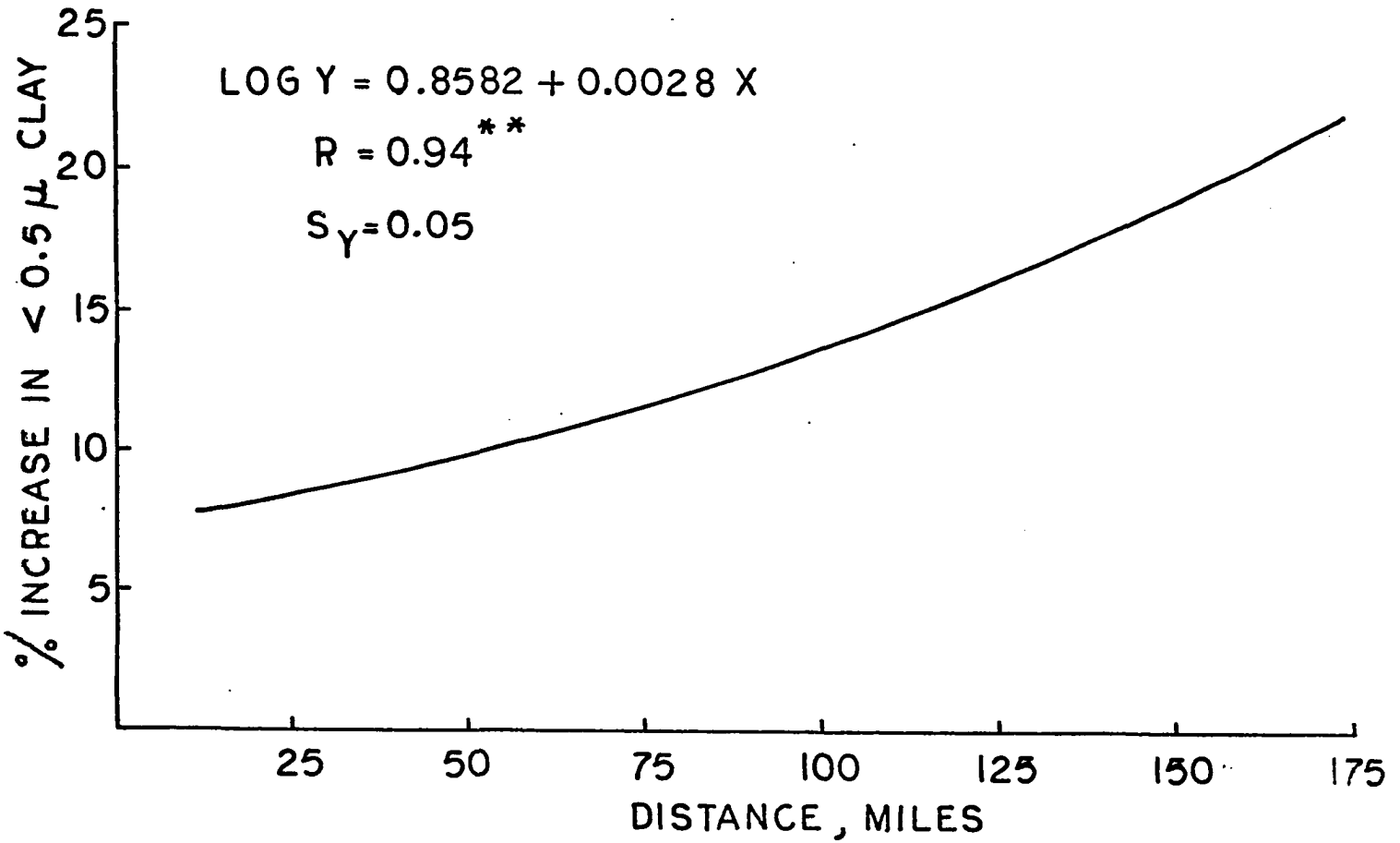

Y = 11.52 + 0.036 X
R = 0.80**
S_Y = 1.76
CLAY INCREASE IN B2, %
20
18
16
14
12
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 23. Relationship between the increase in < 0.5 micron fine clay size fraction in the B2 horizon of maximum accumulation and distance from the loess source area


LOG Y = 0.8582 + 0.0028 X
R = 0.94**
S_Y=0.05
% INCREASE IN < 0.5 μ CLAY
25
20
15
10
5
25
50
75
100
125
150
175
DISTANCE, MILES

material against distance. The equation explains 88 percent of the variability of the data. No such functional relationships could be found in the other two clay fractions, 1 - 2 and 0.5 - 1 microns diameter. Apparently, the bulk of the change brought about by weathering appears in the fine clay fraction, in this study < 0.5 microns in diameter. This can also be seen in Appendix E.

The maximum clay percent in the solum varies from 28.9 nearest the bluffs to 52.0 173.2 miles southeastward. This represents changes of 11.1 and 17.2 percent respectively. A considerable proportion of this change in clay occurs in the fine fraction and is a result of parent material changes.

It is appropriate at this point to propose a mechanism for this weathering in the younger loess deposits on the eastern end of the traverse. Consider first that the calcium and magnesium carbonate content of the initial loess varied from 7.96 percent to 0.69 percent systematically over the traverse. The removal of carbonates and subsequent decrease in pH is known to accelerate the formation and weathering of clay minerals (Glen et al., 1960). Also, based on the statistical predictions made in this investigation, the loess becomes much finer textured with distance from the source area. The mechanism for removal of carbonates is available through the perched water-table and probably increasing infiltration from west to east across the traverse. This could

be the result of decreasing slopes and increasing summit width as discussed earlier. Therefore, it is likely that more available water could remove the originally low amount of carbonates rapidly on the eastern end of the traverse where loess is thin than on the western end of the traverse where it is thick. Once carbonates are removed, clay may form in place or be translocated by percolating water.

Table 8 compares the measured mean percentages of the various size fractions between the leached and unleached zones in the loess. A considerable reduction in the percent of 16 - 31 micron fraction is noted. No other silt fraction changes considerably nor do the 1 - 2 or 0.5 - 1 micron clay fractions. However, the fine, < 0.5 micron, fraction increases markedly with removal of carbonates by leaching. This can be seen from the ratio of leached mean to unleached mean for each fraction. As previously mentioned, the total sand fraction cannot be considered as a sedimentologic fraction. The 31 - 62 micron fraction has a ratio of 0.9390 indicating very small general decrease, the 16 - 31 micron fraction has a ratio of 0.8533 indicating considerable reduction upon leaching. No other silt fraction changes significantly. The coarse clay fraction, 1 - 2 micron, changes little as evidenced by the ratio of 0.9800. The 0.5 - 1 micron, medium clay, increases slightly having a ratio of 1.2311. The greatest change is in the fine clay size frac-

Table 8. Comparison of measured fraction mean values for calcareous and leached loess

Site	Sample[1]	> 62	31-62	16-31	8-16	4-8	2-4	1-2	0.5-1	< 0.5
2	1	0.93	25.28	34.62	13.15	5.14	3.43	3.37	10.38	3.59
2	2	0.87	22.89	30.83	12.64	4.98	3.34	3.25	14.29	7.13
3	1	1.07	25.52	33.52	13.26	4.75	3.76	3.49	9.72	5.10
3	2	0.51	22.30	28.44	13.24	5.35	4.13	3.93	11.79	10.27
4	1	0.94	24.17	32.59	13.64	5.64	3.90	4.05	9.01	5.98
4	2	1.10	23.48	28.01	13.18	5.82	4.60	3.52	10.71	9.81
5	1	1.06	20.18	32.54	15.42	6.77	4.88	4.73	9.87	4.62
5	2	1.00	21.21	28.58	12.88	6.01	4.20	4.51	12.49	9.37
6	1	0.90	15.39	31.99	17.82	7.27	4.76	4.60	10.46	6.81
6	2	0.92	13.93	26.74	17.03	7.83	4.99	4.42	12.58	11.47
7	1	1.17	16.06	31.58	17.50	7.53	4.42	4.51	10.15	7.04
7	2	1.03	14.90	25.50	15.34	7.81	4.33	4.54	11.70	14.95

[1] 1 is mean of calcareous loess
2 is mean of leached loess

tion, that fraction nearly doubling in percent, a ratio of 1.9159, upon removal of carbonates.

It seems unlikely that the clay in loess is transported as individual platelets. It has been reported that clay occurs as coatings and as aggregates in calcareous loess (Davidson and Handy, 1954). It may now seem reasonable to propose that the clay, deposited as such, is dispersed in situ upon removal of the calcium carbonates. Therefore, initial lower carbonate contents of finer textured loess further eastward in addition to the presence of a higher water-table for leaching, could lead to progressively greater dispersion on the east end of the traverse. Then, with a greater amount of clay size particles present and the pH reduced, weathering could be greatly accelerated under the more moist conditions to the east end of the traverse where the loess is thinner.

Mineralogical analysis

If the clay fractions which were measured in the previously discussed particle size analysis are in part a result of dispersion, a lithologic property of the loess, and in part a result of pedogenesis, the mineralogical composition should provide an indication of their origin. Therefore, where possible , X-ray analysis of the < 2.0 micron clay fraction from calcareous loess was run and it was assumed to

represent the mineralogy of the unleached, unweathered loess. This then served as the basis for comparisons of other diffractograms. To evaluate the mineralcgical effects of leaching, a sample of the < 2.0 micron clay from leached loess was subjected to X-ray analysis. This sample was selected to be below the solum and therefore supposedly uninfluenced by pedogenic processes. A sample was also chosen from the zone of maximum clay accumulation and fractionated into 1 to 2, 0.5 to 1, and < 0.5 micron diameter seperates as previously described. The smoothed X-ray diffractcgrams produced from these fraction are shown in Figures 24 through 35. An examination of traces A and B in Figures 24 through 29 indicates the clay minerals present in the original loess parent material and aid in evaluation of the effects of leaching. The predominant clay mineral present at each of these locations is montmorillonite. This is indicated by the pronounced diffraction peaks at 18A 001 spacings. The montmcrillonite is present at all locations and comparison of diffraction peaks of curves A and B indicates no change in intensity or peak width. Therefore, removal of carbonates does not appear to alter the predominant clay mineral significantly.

A 14A 001 spacing is characteristic and diagnostic of vermiculite-chlorite type clay minerals. This peak is apparent at each of the locations as seen in curves A and B.

Figure 24. Smoothed X-ray diffractograms from site number 2. Curve A is < 2 micron clay from calcareous loess 400-405 inches deep, B is < 2 micron clay from leached loess 70-75 inches deep, C is clay from clay maximum at a depth of 20-25 inches and 1-2 micron diameter, D is from the same depth and 0.5-1 micron diameter, E is from the same depth and < 0.5 micron diameter.

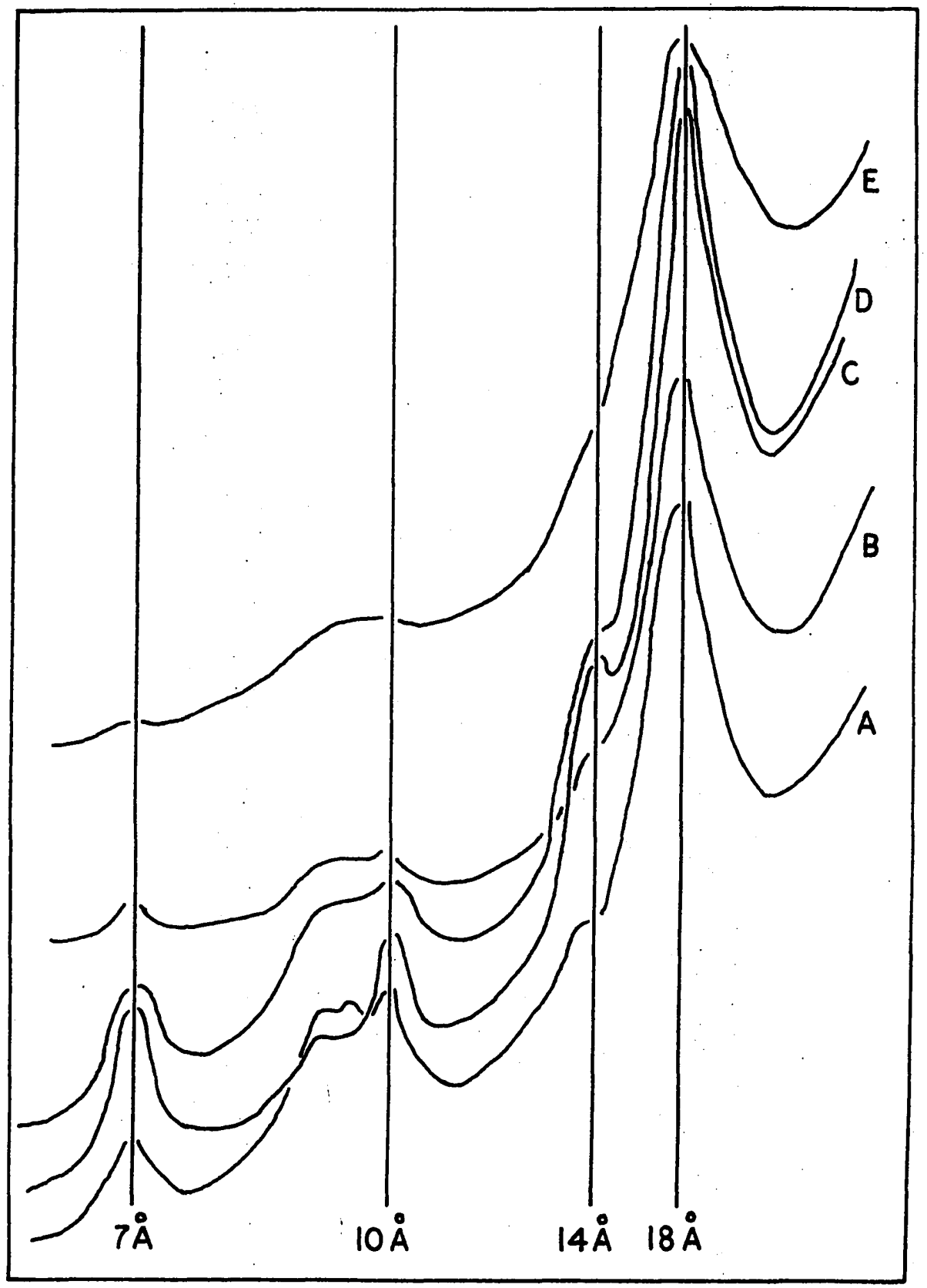

E
D
C
B
A
7Å
10Å
14Å
18Å

Figure 25. Smoothed X-ray diffractograms from site number 3. Curve A is < 2 micron clay from calcareous loess 404-409 inches deep, B is < 2 micron clay from leached loess 76-81 inches deep, C is clay from clay maximum at a depth of 16-20 inches and 1-2 micron diameter, D is from the same depth and 0.5-1 micron diameter, E is from the same depth and < 0.5 micron diameter.

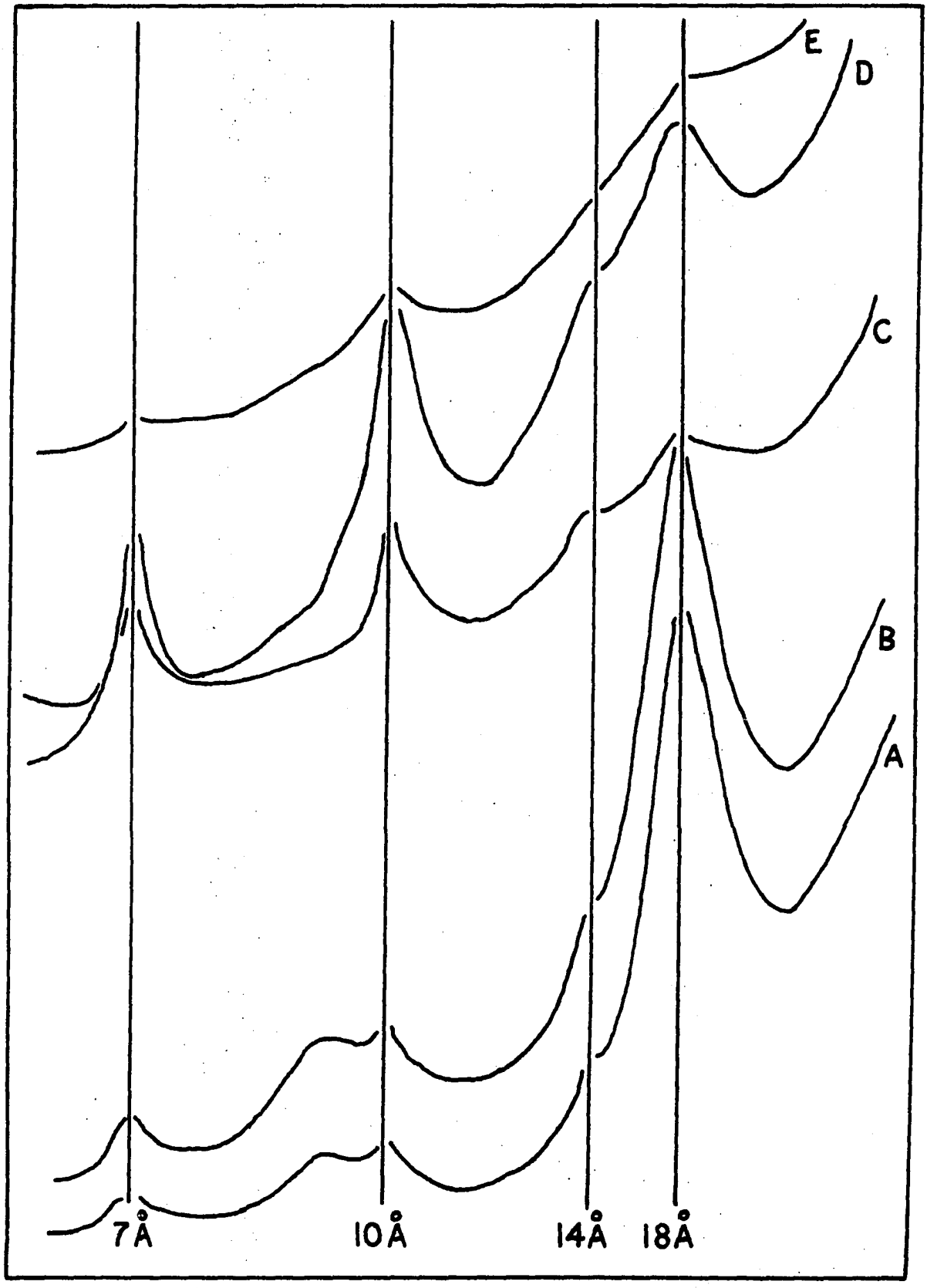

E
D
C
B
A
7Å
10Å
14Å
18Å

Figure 26. Smoothed X-ray diffractograms from site number 4. Curve A is < 2 micron clay from calcareous loess 257-268 inches deep, B is < 2 micron clay from leached loess 99-104 inches deep, C is clay from clay maximum at a depth of 26-31 inches and 1-2 micron diameter, D is from the same depth and 0.5-1 micron diameter, E is from the same depth and < 0.5 micron diameter.

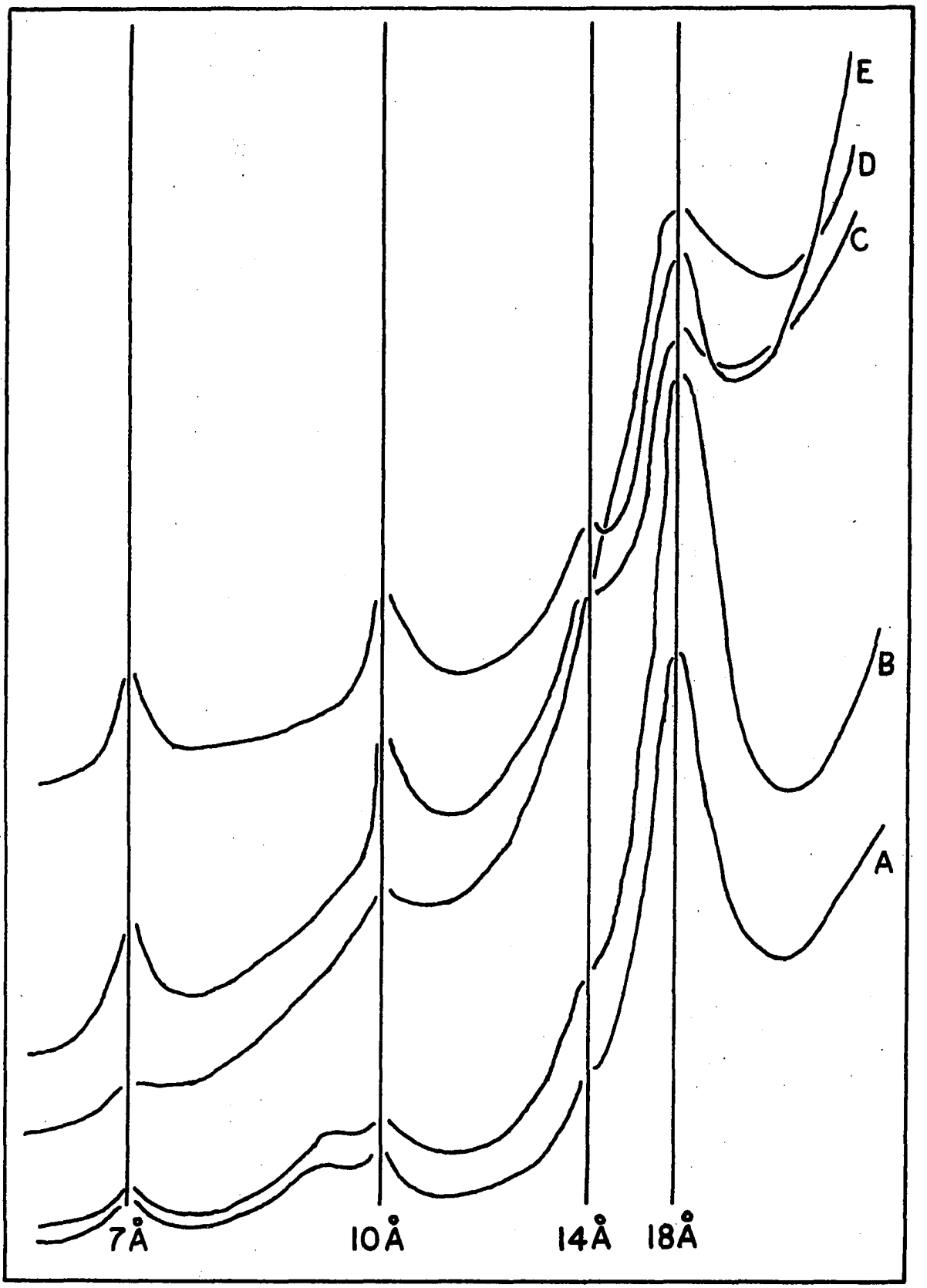

E
D
C
B
A
7Å
10Å
14Å
18Å

Figure 27. Smoothed X-ray diffractograms from site number 5. Curve A is < 2 micron clay from calcareous loess 202-207 inches deep, B is < 2 micron clay from leached loess 63-68 inches deep , C is clay from clay maximum at a depth of 20-24 inches and 1-2 micron diameter, D is from the same depth and 0.5-1 micron diameter, E is from the same depth and < 0.5 micron diameter.

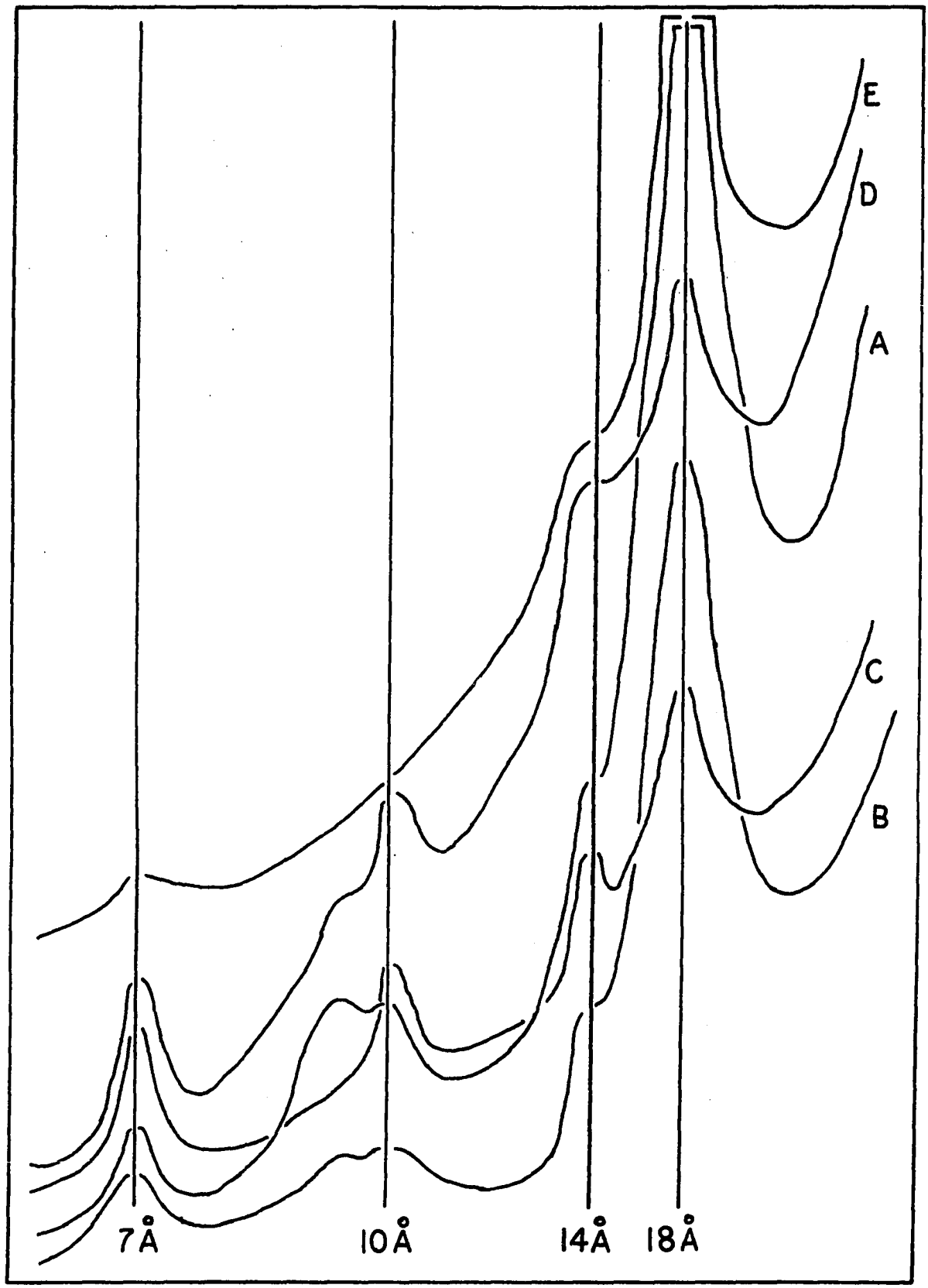

E
D
A
C
B
7Å
10Å
14Å
18Å

Figure 28. Smoothed X-ray diffractograms from site number 6. Curve A is < 2 micron clay from calcareous loess 136-140 inches deep, B is < 2 micron clay from leached loess 84-89 inches deep, C is clay from clay maximum at a depth of 19-24 inches and 1-2 micron diameter, D is from the same depth and 0.5-1 micron diameter, E is from the same depth and < 0.5 micron diameter.

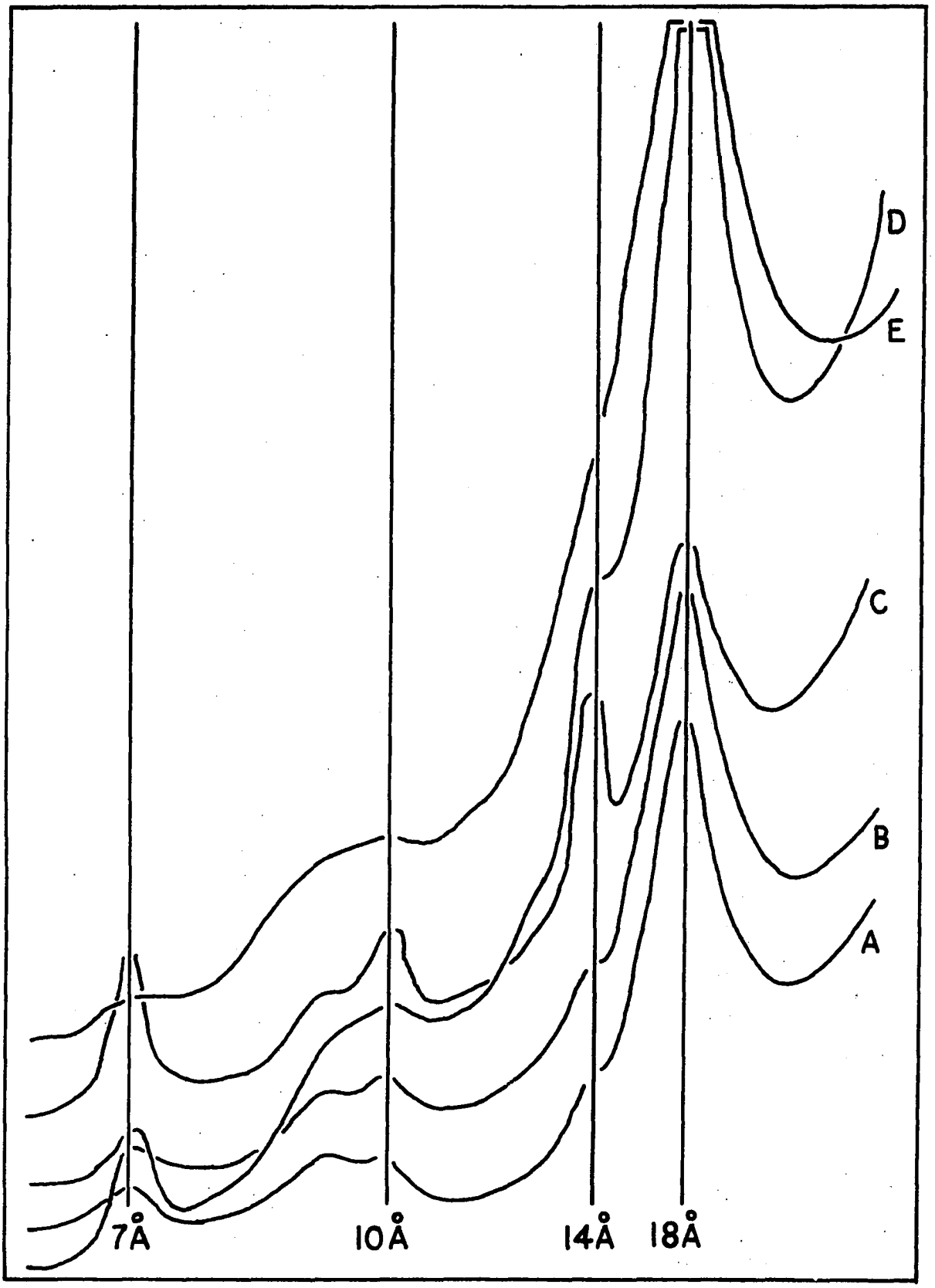

D
E
C
B
A
7Å
10Å
14Å
18Å

Figure 29. Smoothed X-ray diffractograms from site number 7. Curve A is < 2 micron clay from calcareous loess 120-126 inches deep, B is < 2 micron clay from leached loess 75-80 inches deep, C is clay from clay maximum at a depth of 33-38 inches and 1-2 micron diameter, D is from the same depth and 0.5-1 micron diameter, E is from the same depth and < 0.5 micron diameter.

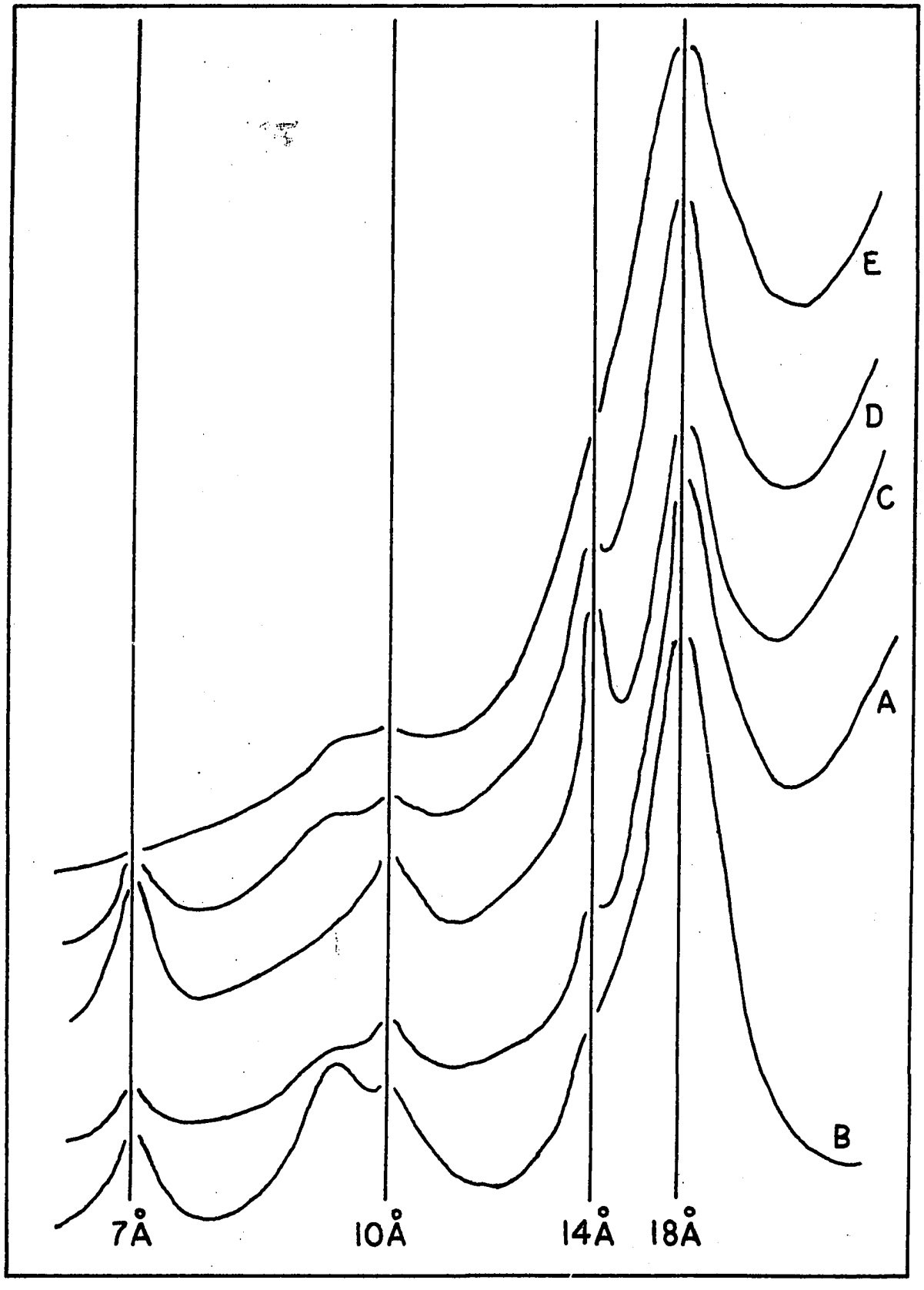

E
D
C
A
B
7Å
10Å
14Å
18Å

Figure 30. Smoothed X-ray diffractograms from site number 8. Curve A is < 2 micron clay from leached loess 93-98 inches deep, B is 1-2 micron clay from clay maximum at a depth of 30-34 inches, C is from the same depth and 0.5-1 micron diameter, D is from the same depth and < 0.5 micron diameter.

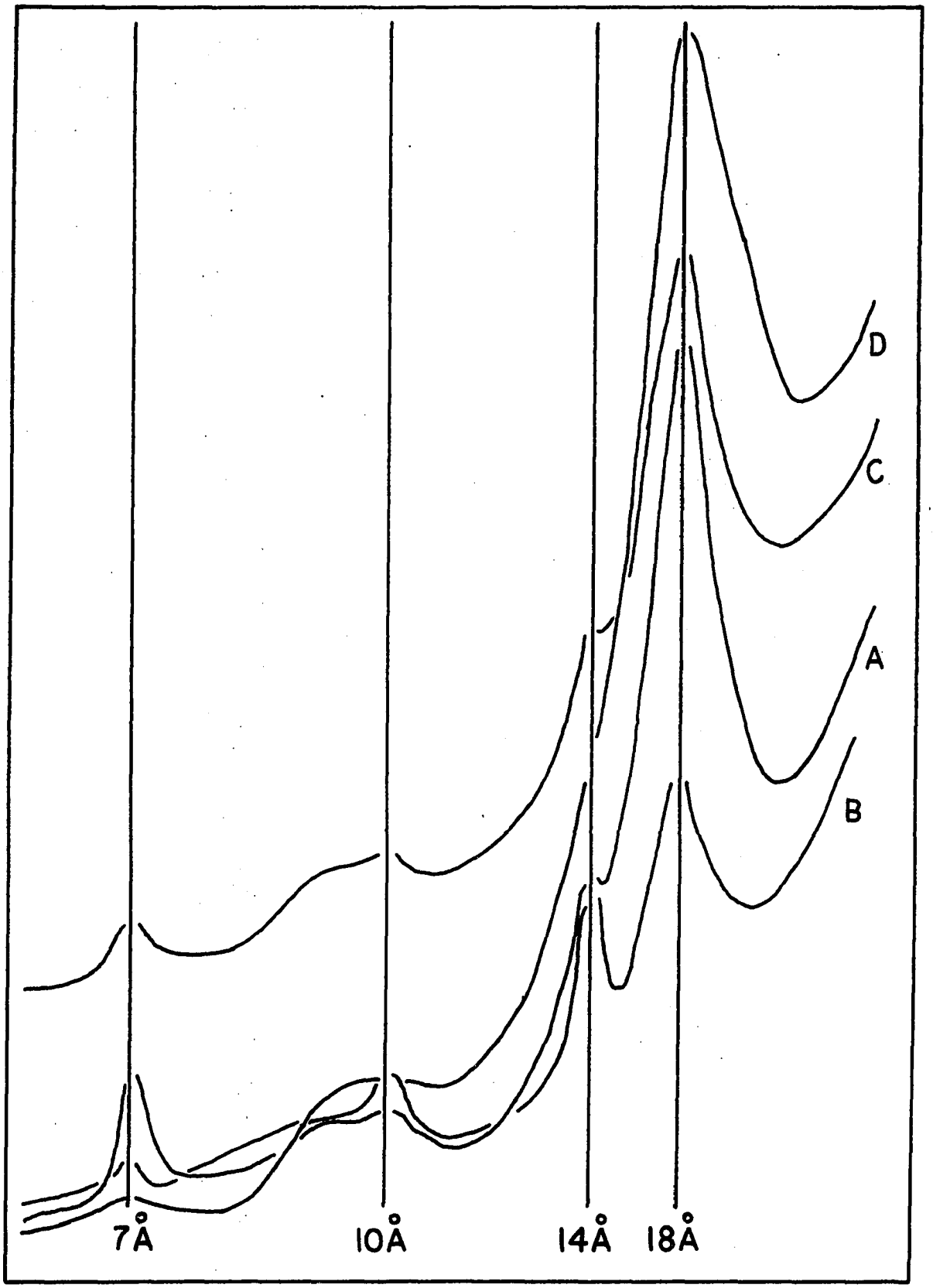

D
C
A
B
7Å
10Å
14Å
18Å

Figure 31. Smoothed X-ray diffractograms from site number 9. Curve A is < 2 micron clay from leached loess 68-73 inches deep, B is 1-2 micron clay from clay maximum at a depth of 25-28 inches, C is from the same depth and 0.5-1 micron diameter, D is from the same depth and < 0.5 micron diameter.

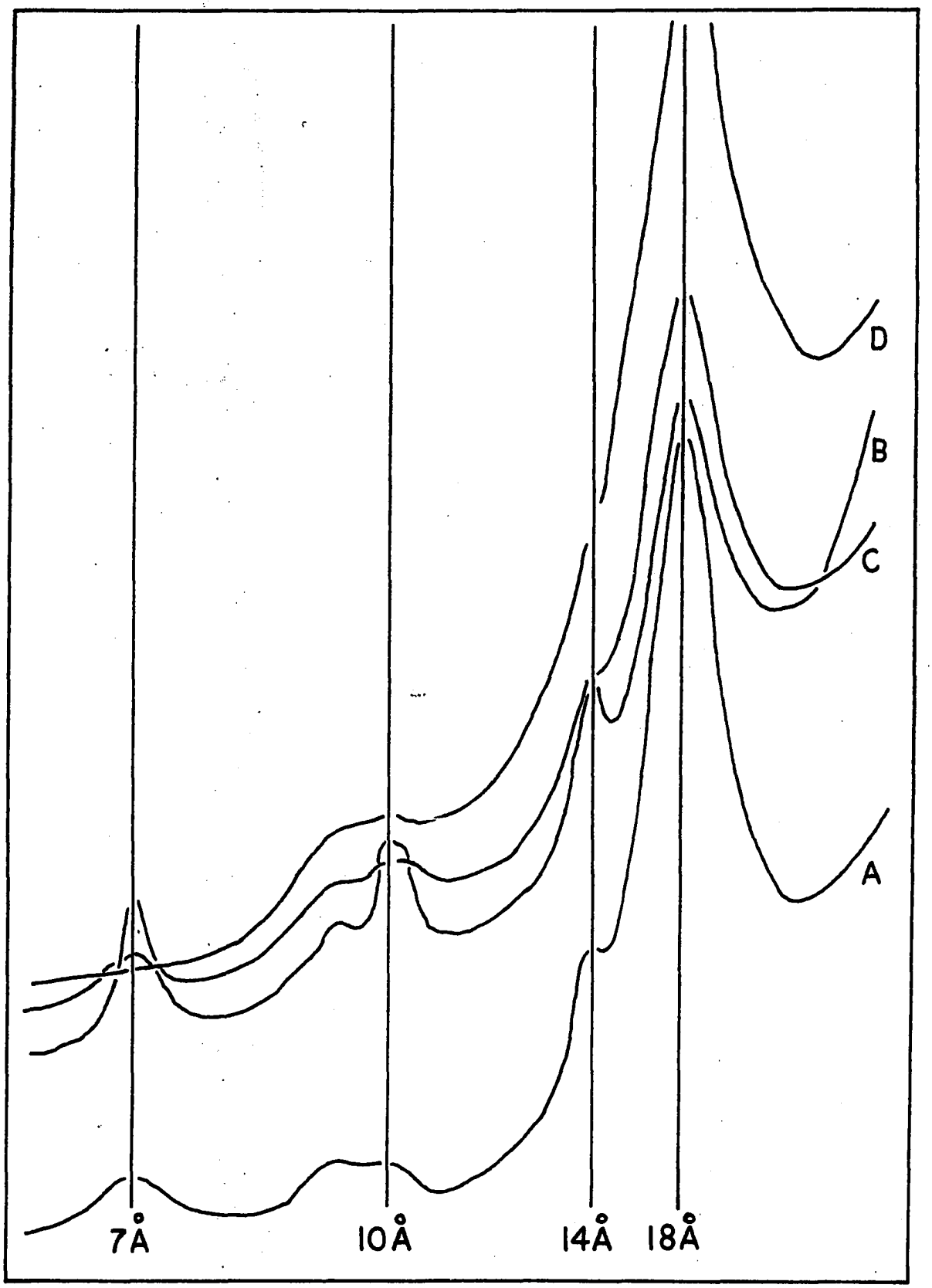

D
B
C
A
7Å
10Å
14Å
18Å

Figure 32. Smoothed X/ray diffractograms from site number 10. Curve A is < 2 micron clay from leached loess 73-78 inches deep, B is 1-2 micron clay from clay maximum at a depth of 22-26 inches, C is from the same depth and 0.5-1 micron diameter, D is from the same depth and < 0.5 micron diameter.

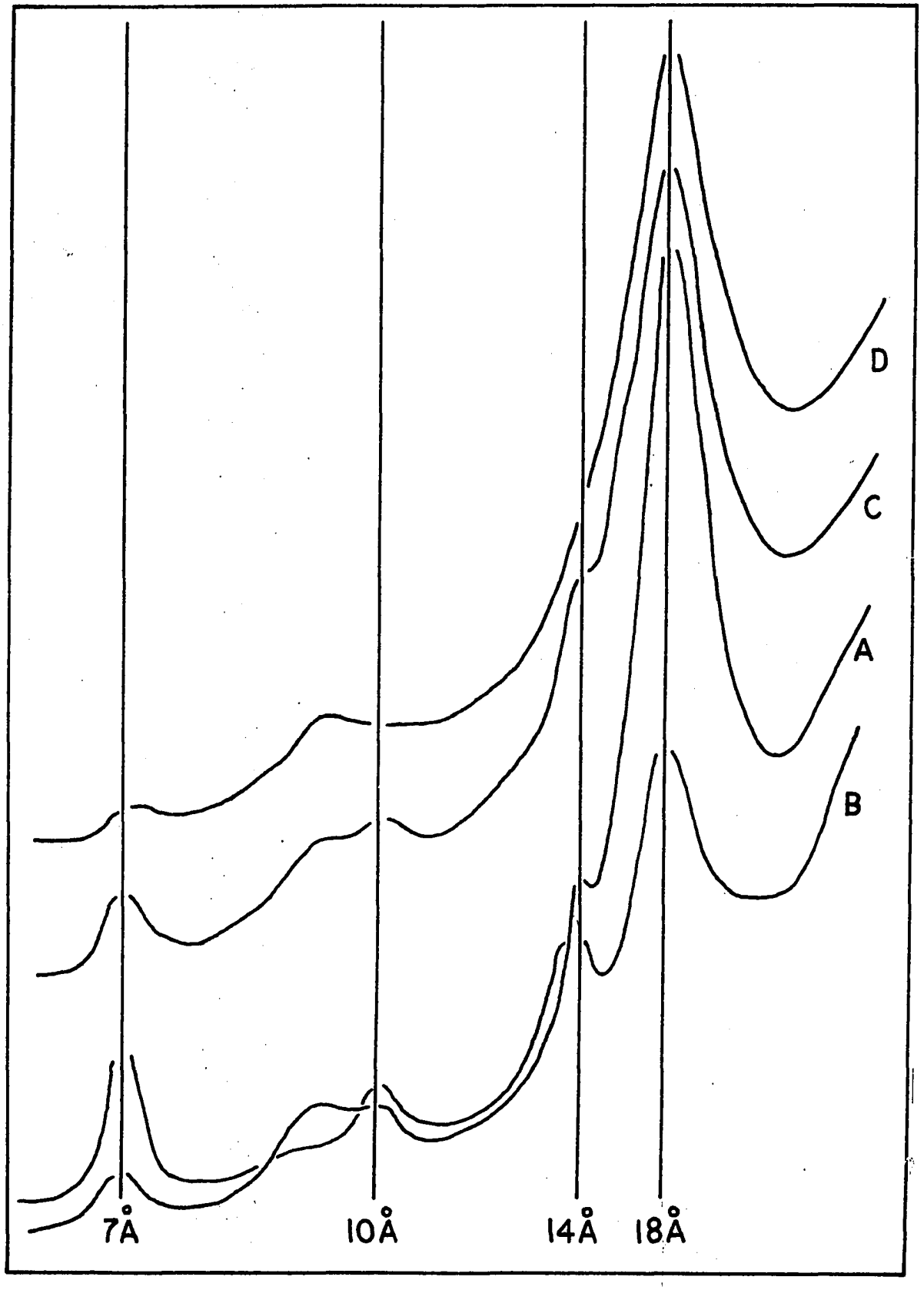

D
C
A
B
7Å
10Å
14Å
18Å

Figure 33. Smoothed X-ray diffractograms from site number 11. Curve A is < 2 micron clay from leached loess 80-85 inches deep, B is 1-2 micron clay from clay maximum at a depth of 17-22 inches, C is from the same depth and 0.5-1 micron diameter, D is from the same depth and < 0.5 micron diameter

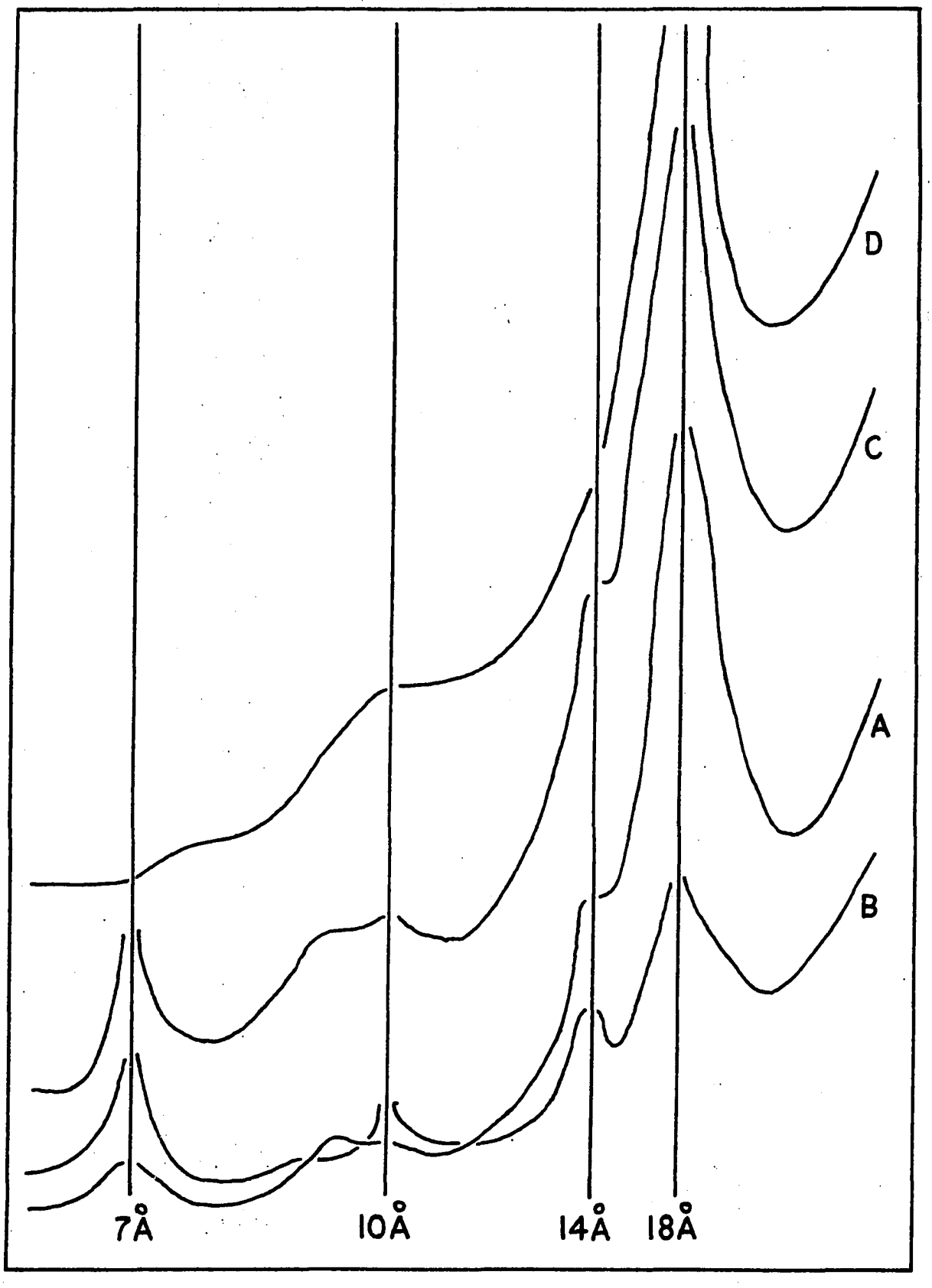

D
C
A
B
7Å
10Å
14Å
18Å

Figure 34. Smoothed X-ray diffractograms from site number 12. Curve A is < 2 micron clay from leached loess 58-62 inches deep, B is 1-2 micron clay from clay maximum at a depth of 24-29 inches, C is from the same depth and 0.5-1 micron diameter, D is from the same depth and < 0.5 micron diameter.

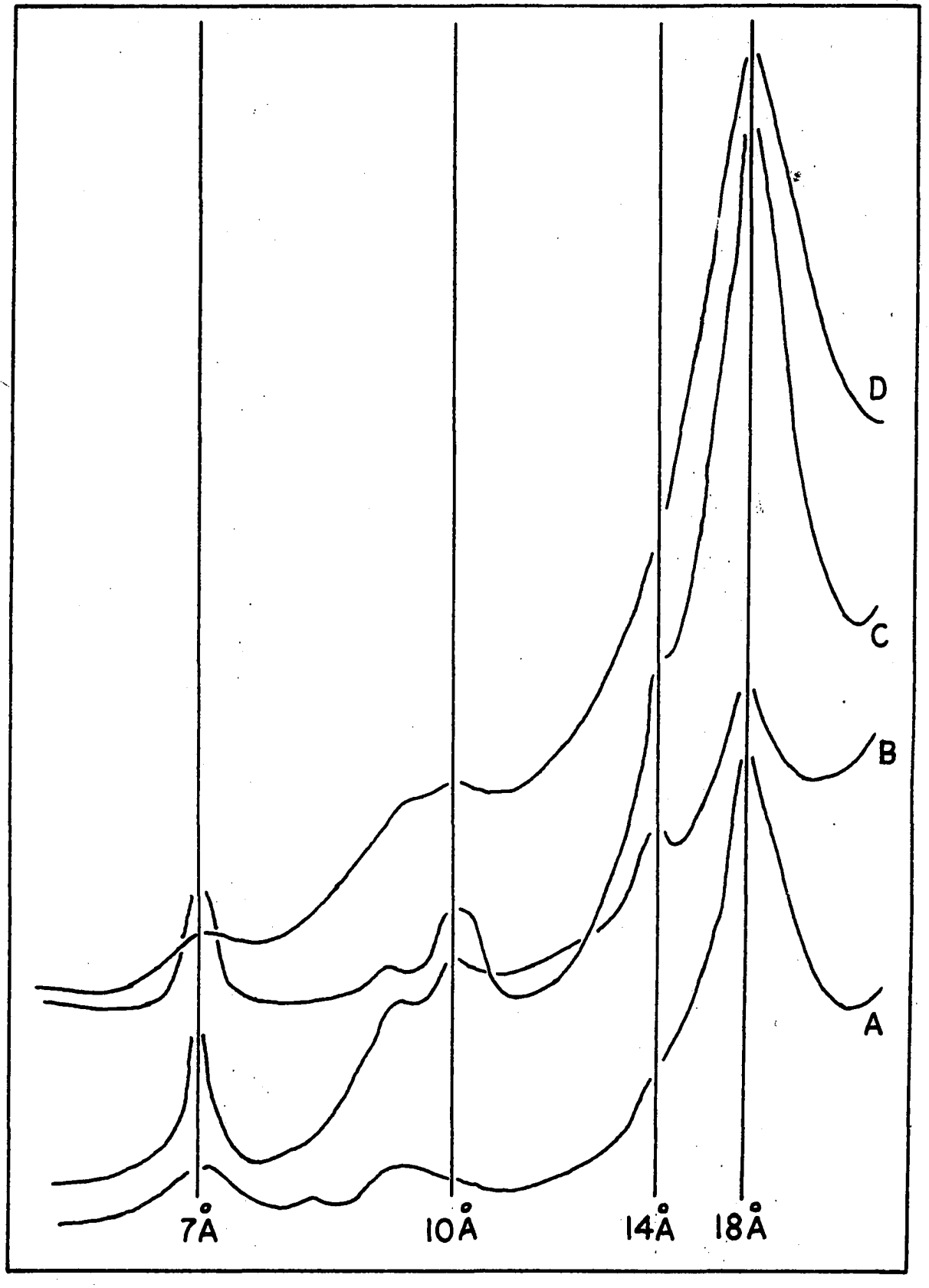
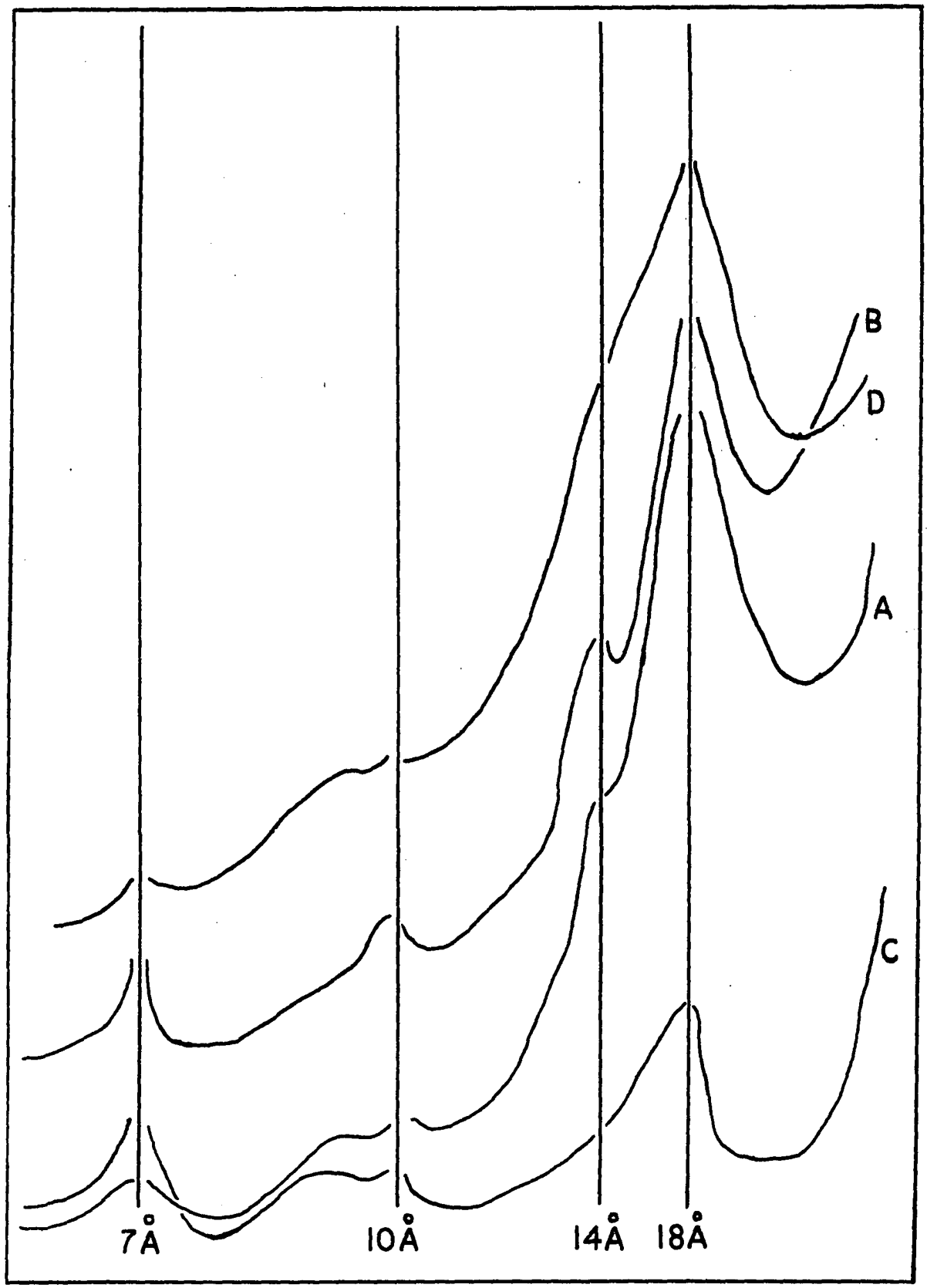

D
C
B
A
7Å
10Å
14Å
18Å

Figure 35. Smoothed X-ray diffractograms from site number 13. Curve A is < 2 micron clay from leached loess 68-75 inches deep, B is 1-2 micron clay from clay maximum at a depth of 21-26 inches, C is from the same depth and 0.5-1 micron diameter, D is from the same depth and < 0.5 micron diameter


B
D
A
C
7Å
10Å
14Å
18Å

This diagnostic peak is of rather low intensity indicating only small amounts of vermiculite present in the samples. Again, removal of carbonate minerals by leaching does not appear to effect this mineral significantly.

The 10A 001 diffraction peak is diagnostic of mica type minerals. This peak shows in curves A and B of Figures 24 through 29 indicating the presence of this type of minerals in the original loess and after leaching. However, the peak at 14 A spacing is not sharp but rather, is diffuse. A diffuse peak of this nature is generally interpreted as an indication of interstratification of the mica type minerals present (Brown, 1961). The peak height and peak width, indicative of intensity, is apparently unaltered by removal of carbonates by leaching. Mica type minerals are present in only small amounts.

Kaolinitic minerals are characterized by a 7A 001 diffraction peak. Since this peak appears, with rather low intensity, on all traces, it may be concluded that kaolinite is present in the original loess but in minor amounts. The kaolinite is unaltered by leaching of carbonates.

Concerning the clay mineral present in the original calcareous loess parent material it may be said that the predominant clay mineral is montmorillonitic. Traces of vermiculite-chlorite type minerals exist. Small amounts of an interstratified mica type mineral are also evident.

Kaolinitic minerals are in evidence in small amounts. Removal of carbonate minerals by leaching appears to leave those minerals unaltered. The removal of carbonates reduced the pH from 7.6 - 7.9 to 6.3 - 6.8. This small reduction in the near neutral range of pH would not be expected to alter clay minerals significantly.

Curve A in Figure 30 through 35 can be related to curve B in Figures 24 through 29 in that they represent the leached loess below the solum. However, as previously noted, alteration of this material has occurred. Therefore, these curves do not represent the original loess mineralogy on the eastern end of the traverse. Montmorillonite is the predominant mineral. The vermiculite-chlorite minerals are present but with decreasing peak intensity eastward indicating less of this mineral type present. Mica decreases considerably in peak intensity. Kaolinite exists as only a trace on the eastern end of the traverse.

The horizon of maximum clay accumulation is represented by curves C, D and E in Figures 24 through 35. Since this is the zone of clay accumulation, it may be expected to represent the zone of maximum alteration of clay minerals. Therefore, the sample from this zone was fractionated into three size fractions for X-ray analysis.

In all three size fractions and at all locations, montmorillonite remains the dominant type clay mineral

present. The 18A peak intensity changes little from the leached loess samples but does increase slightly eastward. Peak width decreases somewhat indicating removal of interlattice components.

The 14A vermiculite-chlorite peak reaches maximum intensity in the 1 - 2 micron size fraction but varies little with distance. This peak is reduced to a shoulder on the dominant 18A peak in the 0.5 - 1 micron fraction and is completely missing in the < 0.5 micron fraction. It is known that vermiculite minerals exist naturally as macroscopic particles but are easily reduced in size by weathering (Brown, 1961). Similarly, vermiculite-chlorite minerals tend to be unstable at very fine size reduction (Brown, 1961). It seems plausible that the vermiculite-chlorite apparent in the < 2 micron leached loess samples is intensified by weathering in the 1 - 2 micron samples. This shows up as greater peak height and smaller peak widths. Further size reduction by weathering destroys this mineral as effected by shorter and wider 14A peaks in the 0.5 - 1 micron samples and finally, absence of this peak from the < 0.5 micron samples.

Mica type minerals are easily weatherable (Brown, 1961). The 10A 001 spacing peak decreases in intensity with distance. At any location, reduction in size essentially eliminates this mineral from the clay size separates. In addition, the peaks become more diffuse with reduction in size

an indication of lattice distortion presumably from weathering. The amount of mica type minerals present in any size fraction where detectable, decreases rapidly with distance away from the source area.

Kaolinite, evidenced by the 7A 001 diffraction peak, accounts for only a trace of the clay minerals present < 2 microns in diameter. With increasing distance from the loess source area, even this trace decreases in abundance. Reduction in size below 0.5 microns completely eliminates kaolinite from the group of clay minerals present. Even though kaolinite exists as a stable clay mineral at pH values in the acid range, it is destroyed by size reduction (Brown, 1961). As discussed in the previous section and shown in Appendix E, the percent clay < 0.5 micron diameter increases rapidly eastward along the traverse. It is therefore reasonable that the kaolinite should decrease in the same direction.

Montmorillonite is the dominant clay mineral present in loess parent material, either calcareous or leached. This mineral remains the dominant species even in the smaller size fractions from the zone of maximum clay accumulation. In fact, montmorillonite is the only mineral present in significant amounts in samples < 0.5 microns diameter. Vermiculite-chlorite minerals exist unaltered in calcareous and leached loess. This mineral appears to weather some in the solum such that much sharper peaks occur in the 1 - 2 micron size

fraction. These peaks are severely reduced in intensity from 0.5 - 1 micron clay and are absent at sizes < 0.5 micron. Apparently, the vermiculite-chlorite minerals are weathered out and further, it appears that the < 0.5 micron clay is genetically related to the coarser size clay fractions. Easily weatherable mica type minerals follow the same trend as do the vermiculite-chlorite type as do the kaolinitic minerals.

It may now be possible to make definitive statements concerning the mineralogy of loess and its alteration by weathering. Removal of carbonates by leaching does not effect the minerals present. On the basis of similarity of X-ray diffractograms, it is apparent that the leached loess is derived from calcareous loess. Further weathering of the loess serves to accentuate the existence of montmorillonite as the dominant mineral present. The decrease in apparent amounts of vermiculite-chlorite, mica and kaolinite minerals seems to be the result of weathering. On the basis of the shift of diffraction peaks with decreasing particle size, it appears that the clay present is, in considerable part, lithologic and the increasing fineness results from size decrease not in situ formation. Some clay may be genetically formed in place, but most seems to be the result of physical and chemical size reduction and dispersion. This is supported by the discussed trends and interrelationships between the

mineralcgy of the various size fraction examined.

Previous investigations of loess have reported that the percent sand content shows a marked increase at great distances from the source area (Hutton, 1948; Ulrich, 1949). It was suggested that this was perhaps the result of including secondary iron - manganese concretions in the > 62 micron fraction. These concretions have been observed in loess (Barnhisel et al., 1971) and felt to increase with increasing degree of soil development(Bray, 1934). The sand size fraction was found to increase in this study as apparent in Figure 12 and from the data in Appendix E. It was decided to examine this sand fraction microscopically to quantify changes in the sand composition with distance from the loess source area. The grains were counted as a three component system; secondary concretions, mica flakes and all other clear or opaque primary grains. The latter appeared to be composed essentially of quartz. The sum of this fraction and the mica was considered as total primary sand and as such, a part of the sedimentologic loess system.

The percent of the sand fractions measured as clear and cpaque primary grains is shown in Figure 36. When the percent sand increases with distance away from the loess source area, the amount of that sand which is primarily sedimentologic, excluding mica, decreases in a systematic manner. The curve is very smooth to a distance of 84.4 miles

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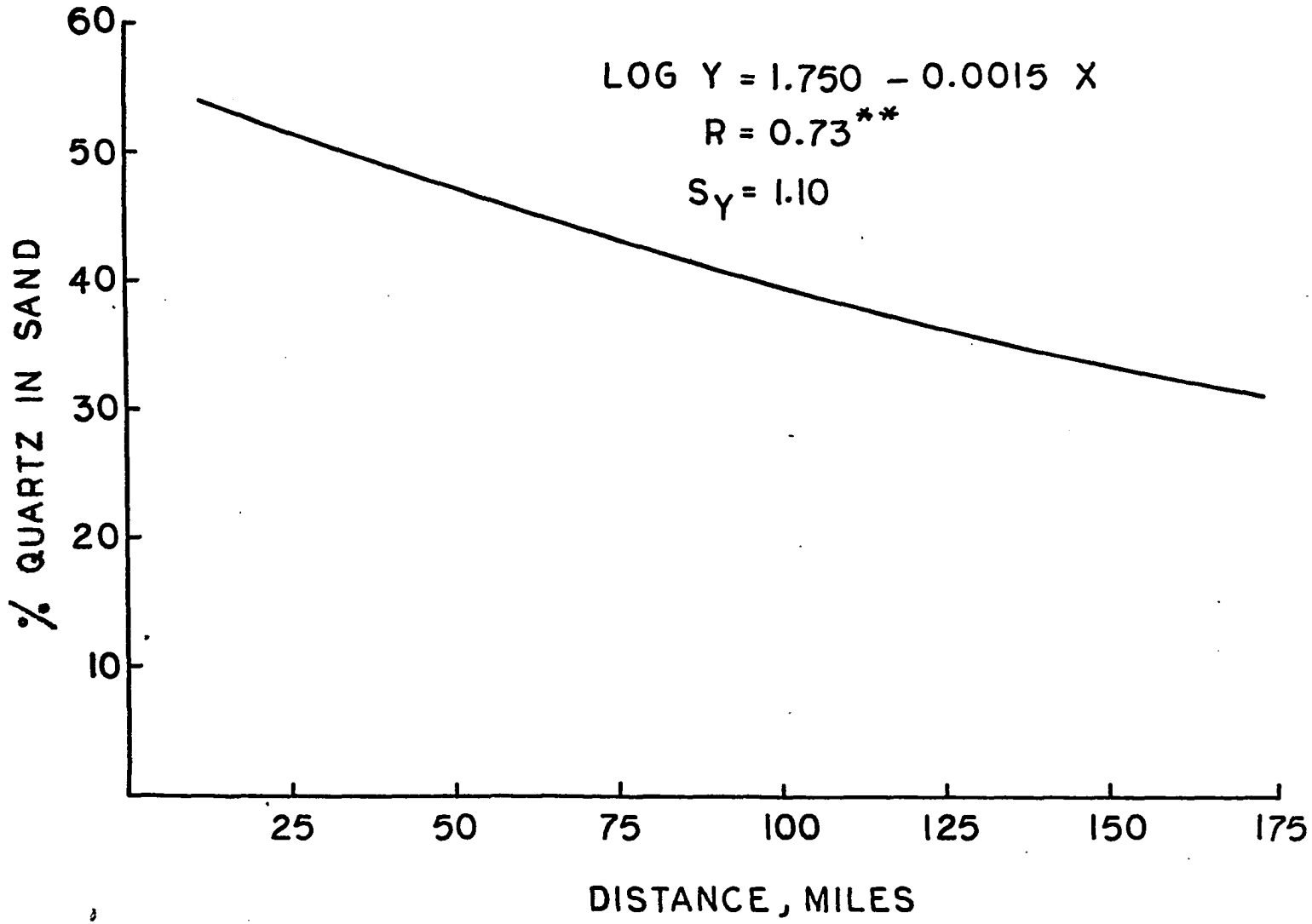
Figure 36. Relationship between percent clear and opaque primary grains in the sand size fraction and distance from the loess source area


LOG Y = 1.750 − 0.0015 X
R = 0.73**
SY = 1.10
% QUARTZ IN SAND
60
50
40
30
20
10
25
50
75
100
125
150
175
DISTANCE, MILES

and then becomes erratic. Observation of these grains under 15 - fold magnification revealed that, eastward along the traverse for 84.4 miles, the sand contained many large quartz grains. These grains were of sufficient size, some as large as 0.5 mm diameter, as to rule out their derivation from the original source area. It is proposed that these sands were of local origin. The sands closer to the source than 84.4 miles were very uniform in size, while those further away were not, the implication again being of a local source. The percent of the sand which was composed of these clear or opaque grains increased rapidly near the underlying palesolic surface. Closer than 84.4 miles, the surface was the Sangamon paleosol developed from Loveland loess, itself a fine textured eolian deposit. At all points eastward, the underlying paleosol was the Yarmouth-Sangamon developed from Kansan till. This appears to be sufficient evidence to conclude that, during the initial stages of loess deposition, considerable sand from the surface upon which the loess was deposited, was mixed with the eolian material from the source area, the Missouri River Valley. Other local sources such as small stream and river flood plains, also contributed considerable sand to the loess throughout the period of deposition.

The mica present in the loess can be considered as being derived from the Missouri River Valley. At no place along the traverse did mica appear in the paleosol. Therefore,

this surface could not have contributed sand size mica to the loess. Figure 37 supports this conclusion. The functional relationship between the percent of the sand which is mica and distance from the source area is very exact, explaining 94 percent of the variability of the data. The mica decreases very rapidly with distance. It is an easily weatherable mineral. The more strongly developed soils have no mica in the solum. Even the minimally developed soils nearest the source area showed marked decreases in mica content in the solum. The decrease in mica in the sand fraction must then be attributed to weathering.

Since both mica and the other clear and opaque grains decrease with distance, the sum of these two must also decrease. This is apparent in Figure 38. The influence of the clear and opaque grains is strongly expressed, particularly on the eastern end of the traverse. This is to be expected since only traces of mica occur there.

Since the percent of the sand grains which may be considered as primary depositional sand decreases with distance from the source area, the percent of the sand which is secondary concretions must increase with distance. This is shown in Figure 39. These concretions must form in place by the translocation of iron and manganese post-depositionally. It could be logically expected that concretions would be associated with the deoxidized zone in the loess since

Figure 37. Relationship between percent mica in the sand size fraction and distance from the loess source area

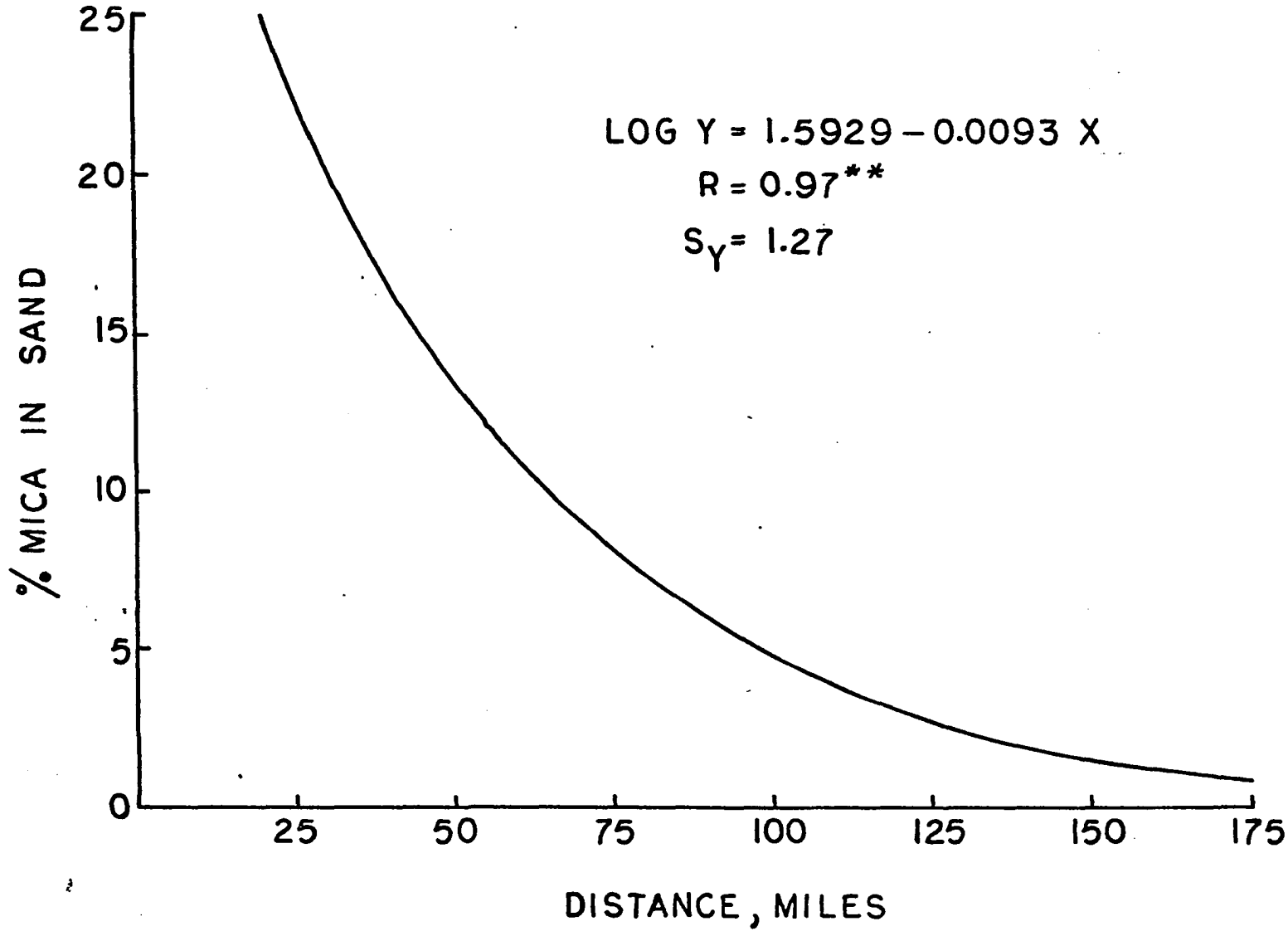

LOG Y = 1.5929 – 0.0093 X
R = 0.97**
S_Y = 1.27
% MICA IN SAND
0
5
10
15
20
25
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 38. Relationship between percent total primary grains in the sand size fraction and distance from the loess source area

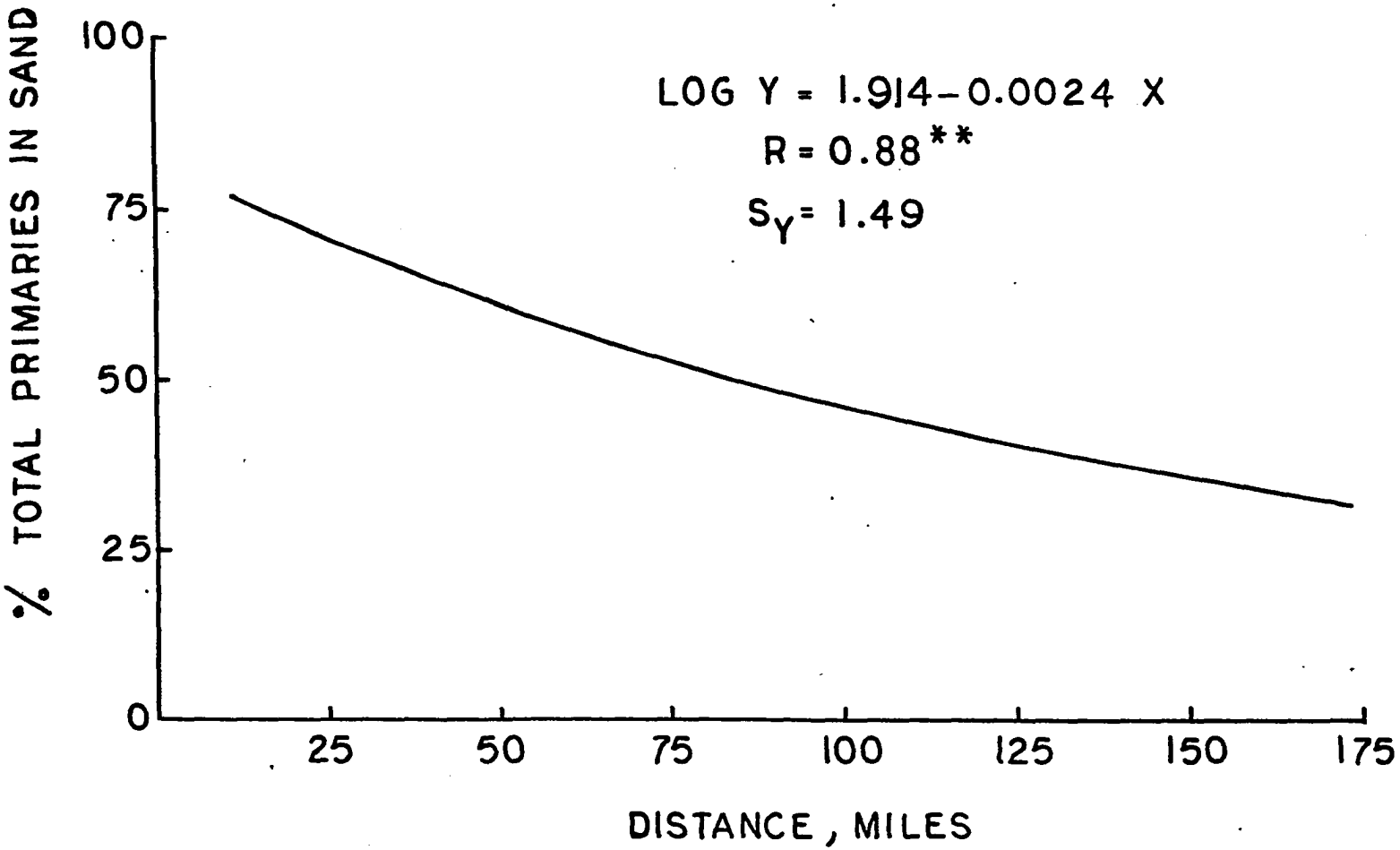
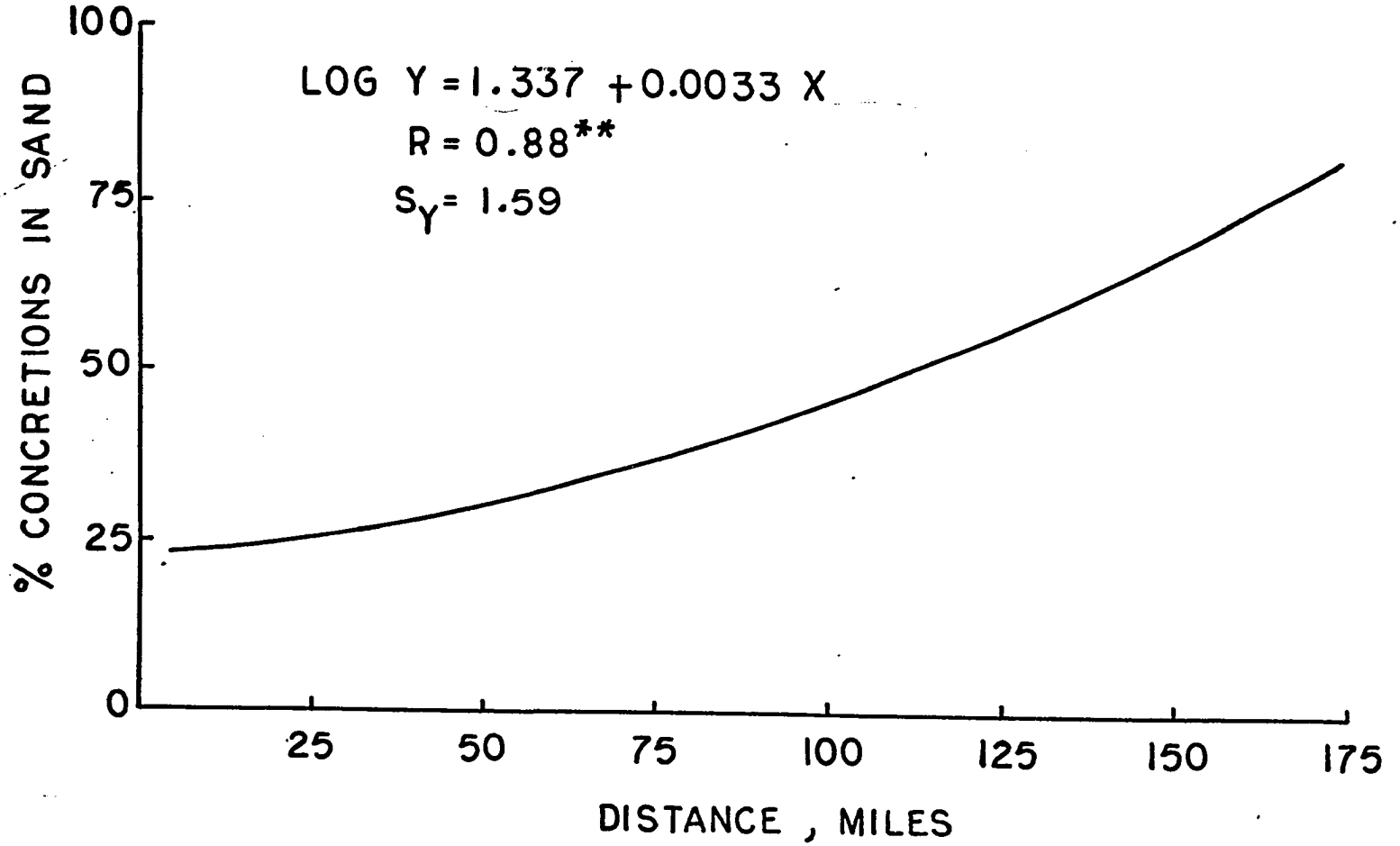

LOG Y = 1.914 – 0.0024 X
R = 0.88**
S_Y = 1.49
% TOTAL PRIMARIES IN SAND
100
75
50
25
0
25
50
75
100
125
150
175
DISTANCE, MILES

Figure 39. Relationship between percent secondary iron-manganese concretions in the sand size fraction and distance from the loess source area


LOG Y = 1.337 + 0.0033 X
R = 0.88**
S_Y = 1.59
% CONCRETIONS IN SAND
100
75
50
25
0
25
50
75
100
125
150
175
DISTANCE , MILES

segregation of iron is a characteristic of this weathering zone(Ruhe, 1969a). The systematic variation does not indicate this to be true if there exists in the loess a definate deoxidized zone with uniform morphology across the loess province. It appears then, that the degree of deoxidation must also vary with distance from the source area. In other words, the degree of deoxidation appears to be part of the overall loess system rather than a discrete entity with no systematic variability.

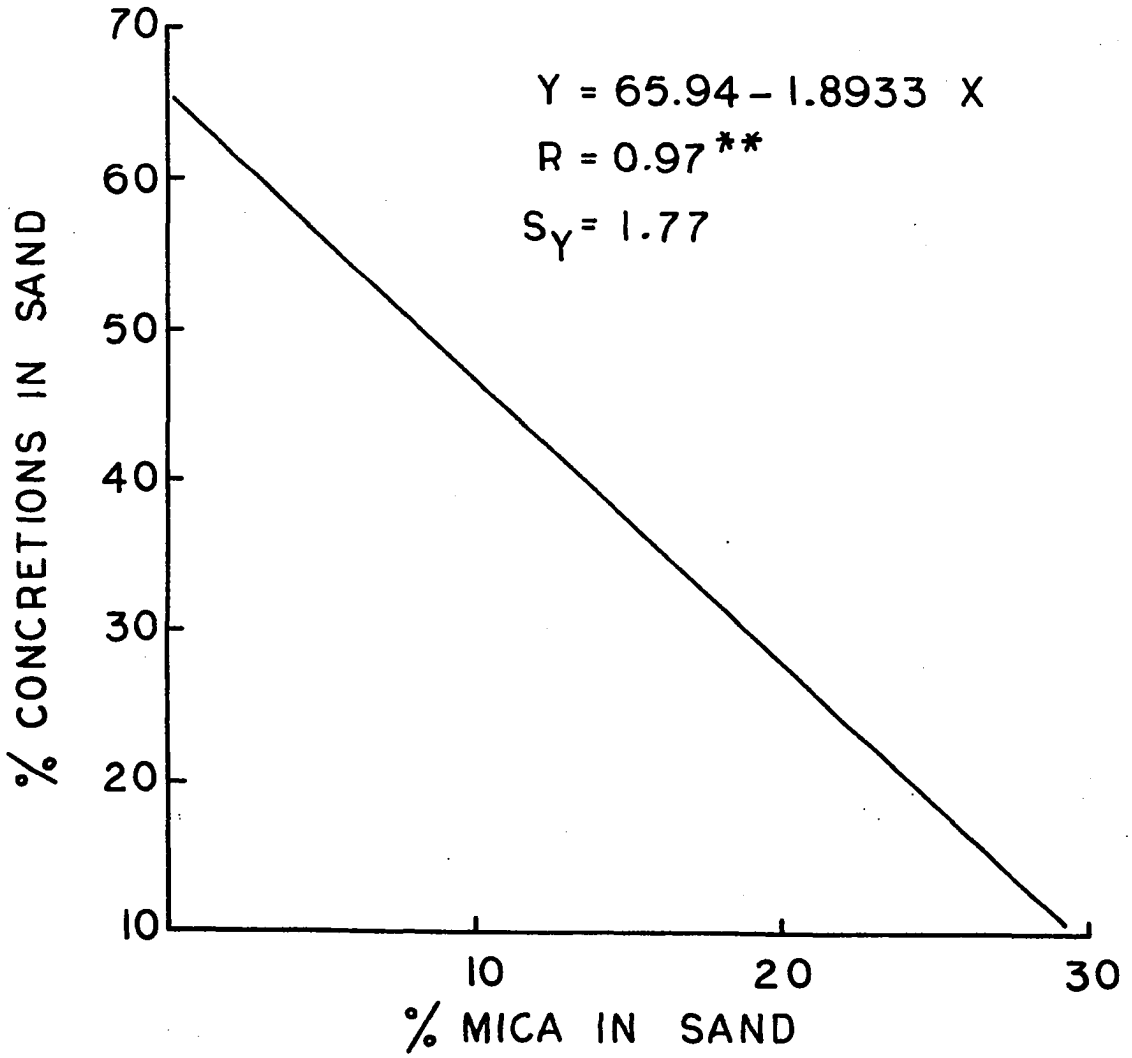
Of the three types of sand grains distinquished in this investigation, only two can be expected to vary with weathering. These are the mica and the secondary concretions. Figure 40 shows the relationship between these two grain types. As the mica content of the sand decreases, the percent of secondary concretions increases. The mica was observed to be predominantly biotite, a ferromagnesian mineral. It is possible that a portion of the iron in the concretions is derived from weathering of this mineral. This contribution would be small most likely. During deoxidation processes, the iron is most likely stripped from individual silt grains and crystallized into concreticnary forms. Irrespective of the original source of iron, both the amount of concretions and mica serve as indications to illustrate the increased degree of development of soil eastward away from the loess source area. The increase in secondary iron-

manganese concretions can reasonably occur only in an increasingly more moist environment. Iron would not be solubalized under the dry conditions of western Iowa, and if it were, there would be no medium for movement. On the eastern end of the traverse, adequate moisture is present to permit movement of iron. Iron must exist in the reduced ferrous state to be soluble and hence mobile. Waterlogging can produce these conditions (Alexander, 1961). Exposure to a oxidative environment can result in oxidation to the insoluble, imobile ferric state of iron. Therefore it is likely that the perched water-table has exerted considerable influence on the formation of secondary iron-manganese concretions in the loess. Furthermore, the systematic relationship between concretions and mica could lead to the conclusion that this water-table is also an important factor in weathering of loess to develop the soils on the present surface.

Free iron and manganese distribution

The weathering cf loess in place was shown to influence the distribution and frequency of secondary iron-manganese concretions in the sand size fraction of the material. It is then logical to assume that the iron and manganese have been redistributed in other size fractions. In addition the solubility of these should be affected also. The raw data is

Figure 40. Relationship between secondary iron-manganese concretions and primary zica in the sand size fraction


Y = 65.94 – 1.8933 X
R = 0.97**
S_Y = 1.77
% CONCRETIONS IN SAND
70
60
50
40
30
20
10
10
20
30
% MICA IN SAND

given in Appendix F and the statistical summary is shown in Table 9. The average percent of citrate-dithionite soluble iron, free iron, tends to increase slightly away from the loess source area. Free manganese, from the same extraction procedure, also shows an increase with distance. Of more interest is the standard deviation and coefficient of variation of the data. Both of these statistics measure the dispersion of the data about the mean value. The absolute dispersion, or standard deviation, increases with distance away from the loess source area for both the iron and manganese. The relative dispersion about the mean, or coefficient of variation, shows the same trend for iron and emphasizes it for manganese.

The primary characteristic used to separate oxidized from deoxidized loess is the distribution of iron within the matrix (Ruhe, 1969a). By definition, deoxidized loess has the iron removed from the silt grains and translocated into segregations. Ruhe (1969a), in discussing the southwestern Iowa loess province, presents an equation which indicates that the deoxidized zone merges with the present surface at a loess thickness of 160 inches. The implication is that the zone is identical, morphologically, at any point where it is encountered. If this is true, then the vertical distribution of free iron and associated manganese should be identical within the deoxidized zone at any location. As is obvious

from Table 9, this is not the case. The process of deoxidation must involve redistribution of these elements within the loess. There is no apparent reason for this redistribution to have a vectorial property, but rather it would be expected to occur randomly throughout the matrix. Therefore, the redistribution of iron associated with deoxidation should be reflected in vertical or horizontal sampling. The increasing deviation with distance from the loess source area indicates , then, that the deoxidized zone is a systematic feature of the loess and increases with distance. It therefore seems unrealistic to discuss this weathering zone in southwestern Iowa as a continuous, monolithic feature. Rather, deoxidation, as shown by variability in the free iron and manganese distribution, should be viewed in degrees of alteration. This fits the system of alteration or weathering as reflected in soil morphology, increasing with distance from the loess source area.

If the deoxidized loess can be viewed in this manner, then it also must be related to a unifying mechanism for leaching, solubalization and movement of constituents. This mechanism can only be moisture present in the loess over extended periods of time. The association must then be with the perched ground-water zone above the paleosols which underly

Table 9. Free iron and manganese distribution statistics along the research traverse

Site	Iron			Manganese		
	Mean	Std. Dev.	C.V.	Mean	Std. Dev.	C.V.
2	0.96	0.25	25.04	0.06	0.07	116.70
3	0.84	0.44	52.37	0.06	0.04	66.67
4	0.95	0.30	31.58	0.08	0.05	62.50
5	0.90	0.40	44.44	0.07	0.04	57.14
6	1.02	0.30	29.41	0.08	0.03	37.50
7	1.00	0.43	43.00	0.08	0.03	37.50
8	1.16	0.34	29.31	0.06	0.03	50.00
9	1.29	0.78	60.47	0.07	0.05	71.43
10	1.01	0.60	59.41	0.08	0.08	100.00
11	0.70	0.41	58.58	0.05	0.05	100.00
12	0.95	0.31	32.63	0.09	0.16	177.78
13	1.20	0.76	63.33	0.09	0.08	112.50

the loess. Its influence on the weathering of the loess appears to be very great as suggested by earlier workers, (Bray, 1934, 1935, 1937; Hutton, 1948; Ruhe, 1969b).

CONCLUSIONS AND SUMMARY

This study was initiated to evaluate the applicability of the effective age concept of loess soil development in southwestern Iowa. This reappraisal was done in light of recent radiocarbon chronology of the loess system which appeared to contradict this concept on the basis of depositional chronology. Another objective was to introduce ground-water as an important factor in the genesis of these loess derived soils.

Field sites were chosen on stable upland primary divide summits along a geographically curvilinear traverse in the southwestern Iowa loess province. Field measurements of these sites revealed that the loess thickness decreased very systematically, following a hyperbolic equation, with distance. The width of the summits also decreased with distance away from the loess source area, the Missouri River Valley. The combination of these factors contributed to the ground-water table approaching the present surface with decreasing loess thickness. This zone of saturation existed above the subjacent Sangamon and Yarmouth-Sangamon paleosol.

Radiocarbon dating indicated that the loess actually became younger at its base further away from the source area. Since it was assumed that the surface of the loess was of a uniform age across the entire loess province, the thinner loess on the eastern end of the traverse was deposited in

less time and more recently than the thicker loess. This is in direct opposition to the effective age concept of uniform time of loess deposition.

At the time of loess deposition, it was apparently calcareous at all locations. Presently the carbonates were detected only 84.4 miles south eastward from the source area. On the basis of the system of calcium carbonate content of the loess, it was predicted that the carbonate content of the original loess would vary from 7.96 to 0.69 percent from the loess bluffs to a distance of 173.2 miles away.

The original loess increments accumulated slowly as evidenced by the accumulation of organic carbon in the basal soil of the Wisconsin loess. During the initial stages, deposition was interrupted by periods of erosional activity and non-deposition. The sand content of the lowest increments of loess is higher than later increments. In addition, the primary sand grains are large and not frosted indicating that this material was not transported great distances by eolian activity. This sand must have come from the paleosolic surfaces upon which the loess was being deposited. On the estern end of the traverse, large sand grains, essentially quartz, appear throughout the loess. Local sources such as stream flood plains and eroded side slopes were most likely the source of this material. The micaeous sand fraction decreased rapidly from west to east. This fraction can be

considered as sedimentologic and derived from the Missouri River Valley. The decrease with distance can be attributed to deposition and subsequent removal by in situ weathering.

The particle size distribution within the present calcareous loess is very systematic with distance. At any particular site, however, deviation from mean values is small indicating slight post-depositional alteration. On this basis, original parent material composition was predicted. The > 62 micron sand size fraction increased with distance. This was related to an abundance of secondary iron-manganese concretion, a non-depositional characteristic. The 31 - 62 and 16 - 31 micron silt fractions decreased with distance. All other silt fractions increased in percent with distance from the source area. The three clay size fractions also increased with distance. At the time of deposition, then, the loess became finer textured with distance away from the source area and the percent calcium carbonate equivalent decreased to a relatively low level.

On the basis of X-ray diffraction analysis of the clay fractions, it was inferred that the depositional clay occurred as aggregates of silt size and as coating on the silt size particles. This aggregation and coating effect was enhanced and stabilized by the carbonates present in the original loess. The predominant clay mineral present was montmorillonite. This remains predominant even after weath-

ering. Minor amounts of vermiculite-chlorite, interstratified micas and kaolinite were found. As evidenced by X-ray diffractograms of clay from the zone of maximum clay accumulation, weathering alteration reduces all minerals present except montmorillonite which is enhanced.

As a result of the relatively impermeable paleosols which are immediately subjacent to the loess, a zone of ground-water saturation exists in the loess itself. It occurs at considerable depths in the thick loess but approaches very close to the surface as the loess thins southeastward. In fact, in the thinner loess, it stands in the soil solum itself. Removal of accumulated water is a function of summit width as it affects hydraulic gradients and distance of lateral movement under these gradients.

Alteration of the loess must begin with removal of the carbonates by leaching. Again the configuration of the summits is important in infiltration or runoff characteristics of each site, wider, flatter summits in the east being the most conducive tc infiltration. The original carbonate content is also important. When calcareous loess exists presently, a relationship is found between the amount of the loess which is calcareous and distance from the source area. No such relationship was found with depth of leaching. It appears that the loess containing the least amount of carbonates is leached most rapidly and completely. An immediate

consequence of this leaching is a change of particle size distribution. The 16 - 31 micron silt fraction decreases in percent while the remaining silt size fraction remain essentially unaltered. The coarse clay changes slightly, medium clay increases slightly and the fine clay size fraction nearly doubles in percent. It is proposed that leaching of carbonates and the presence of a moist enviornment from the perched water-table results in the dispersion of clay platelets in situ. The decrease in carbonates and resultant decrease in pH would also serve to accelerate weathering and formation of clay minerals. This is seen in the disappearance of several clay mineral types and the predominance of montmorillonite minerals in weathered soil profiles.

Therefore, where loess is thin and the original carbonate content was low, weathering is most pronounced. A definite factor is the presence of the ground-water table close to the surface. A considerable portion of the clay present is a lithologic property of the original loess. It does, however, increase with distance and degree of development of the soil. This increase in clay is most evident in the fine fraction and appears to be the consequence of accelerated weathering as discussed.

An optical examination of the sand size fraction revealed that the resistant grains decreased with distance

from the source area. These grains also showed the influence cf local sources of sand during deposition. Primary mica grains decreased logarithmically with distance. Concurrently, secondary iron-manganese concretions increased with distance. A very close linear relationship existed between these grains. Both indicate increased weathering from west to east.

Free iron and manganese increased slightly with distance indicating a change from original primary ferromagnesian mineral forms. Presumably, the only media present which could solubilize and transport iron and manganese would be the ground-water table. As indicated by deviation of the data from mean values, the iron and manganese have been progressively more redistributed on the eastern end of the traverse than the west end. This more random distribution, closely associated with the occurrence of the secondary sand grains, indicates more alteration of the original loess eastward from the source area. This deviation also permits viewing the deoxidized zone as a systematic variable rather than as a strictly monolithic body as has been done previously. The presence and variation within this weathering zone may be seen as indicative of degree of alteration. Since the process of deoxidation has been associated with saturation by water, the present perched water-table is implicated in formation of soils on the present surface.

On the basis of this investigation, it may be concluded that the effective age concept of soil development in loess is not valid in southwestern Iowa. Its credulity is questioned by the radiocarbon chronology established in Iowa and related to loess deposition. An alternative proposal is offered which emphasizes sedimentologic changes in parent material, the geomorphology of the loess province and introduces a stratigraphically associated perched zone of groundwater saturation as being one of the most important factors in loess alteration and soil genesis.

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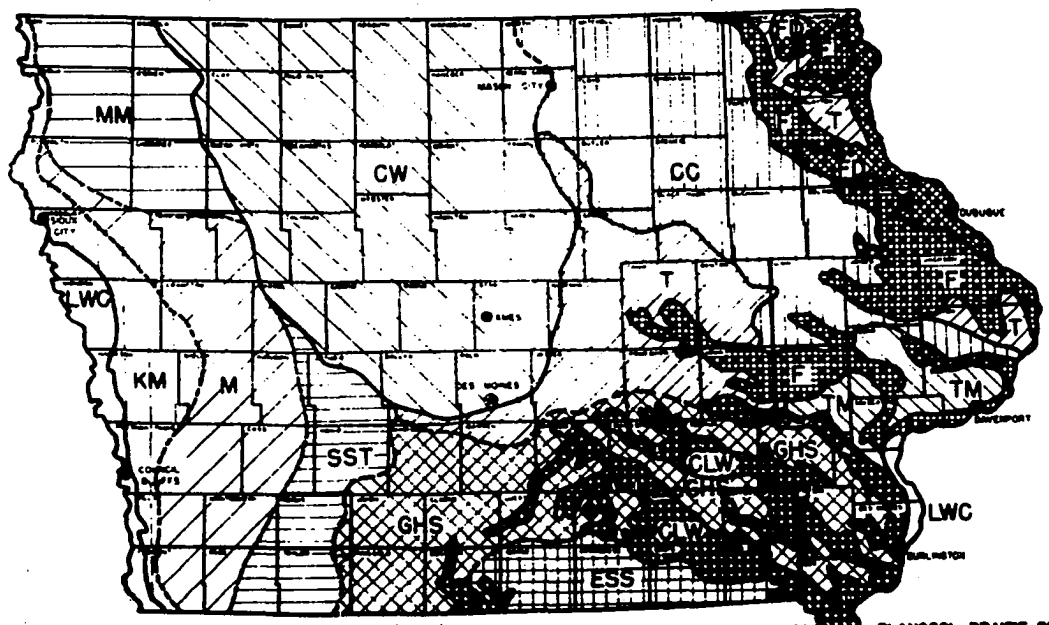
APPENDIX A

ORIGINAL SOIL ASSOCIATION MAP OF IOWA

Reproduction of R. W. Simonson's 1943 soil association map of Iowa. This map is currently unpublished and was provided by F. F. Riecken for its inclusion in this thesis.

SOIL ASSOCIATIONS IN IOWA



PRAIRIE SOILS
CC CARRINGTON-CLYDE
CW CLARION-WEBSTER
KM KNOX-MONONA
M MARSHALL
MM MARCUS-MARSHALL

SST SHARPSBURG-SHELBY-TAMA
T TAMA
TM TAMA-MUSCATINE
ALLUVIAL SOILS
LWC LAMOURE-WABASH-CASS

GRAY-BROWN PODZOLIC SOILS
CLW CLINTON-LINDLEY-SHELLER
F FAYETTE
FD FAYETTE-DUBUQUE

PLANOSOL-PRAIRIE SOILS
GHS GRUNDY-HAMS-SHELBY
ESS EDINA-SEYMOUR-SHELBY

R.W.S.
March, 1943

APPENDIX B:

SOIL PROFILE DESCRIPTIONS

SITE NO.: 2 SOIL SERIES: Monona

LOCATION: NW1/4 SE1/4 sec. 27, T.97N., R.42W., Harrison County, Iowa.

PARENT MATERIAL: 606 inches of Wisconsin loess over a Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-8"	Very dark brown (10YR 2/2) silt loam; weak fine granular structure; friable; clear boundary.
A3	8-18"	Dark brown (10YR 3/3) silt loam; weak fine granular structure; friable; clear boundary.
B1	18-26"	Dark yellowish brown (10YR 4/4) silt loam; weak fine subangular blocky structure; friable; clear boundary.
B2	26-40"	Dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/4) silt loam; weak fine subangular blocky structure; friable; clear boundary.
B3	40-50"	Yellowish brown (10YR 5/4) silt loam; very weak fine subangular blocky structure; friable; clear boundary.
C1	50-90"	Yellowish brown (10YR 5/5) silt loam; few fine distinct yellowish brown (10YR 5/6) and light gray (5Y 7/1) mottles; massive structure; friable; abrupt boundary.
C2	90-137"	Light yellowish brown (10YR 6/4) silt loam; few fine distinct dark brown (10YR 3/3) mottles; massive structure; clear boundary; calcareous.

C3	137-264"	Yellowish brown (10YR 5/4) silt loam; many fine distinct yellowish brown (10YR 5/6) and light olive gray (5Y 6/2) mottles; massive structure; clear boundary; calcareous.
C4	264-324"	Yellowish brown (10YR 5/4) silt loam; common medium distinct light olive gray (5Y 6/2) and yellowish brown (10YR 5/6) mottles; massive structure; clear boundary; calcareous.
C5	324-428"	Light olive brown (2.5Y 5/4) silt loam; common coarse distinct light olive brown (5Y 6/2) and few medium distinct yellowish brown (10YR 5/6) mottles; massive structure; friable; abrupt boundary; calcareous.
C6	428-482"	Olive (5Y 5/4) silt loam; massive structure; friable; clear boundary; calcareous; Fe-Mn zone from 428 - 436 inches; it is yellowish brown (10YR 5/6).
C7	482-496"	Light olive brown (2.5Y 5/6) silt loam; many fine black Fe-Mn specks; massive structure; friable; clear boundary; calcareous.
C8	496-515"	Olive (5Y 5/4) silt loam; massive structure; friable; abrupt boundary; calcareous.
C9	515-606"	Olive (5Y 5/3) silt loam; massive structure; friable; abrupt boundary; small organic carbon flecks from 600 to 606 inches indicates the basal soil of the Wisconsin loess.
IIB1	606-612"	Yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/4) silty clay loam; few fine distinct strong brown (7.5YR 5/6) mottles; firm to friable; Sangamon paleosol.

SITE NO.: 3 SOIL SERIES: Monona

LOCATION: SE1/4 NE1/4 sec. 12, T.79N., R.41W., Harrison County, Iowa.

PARENT MATERIAL: 528 inches of Wisconsin loess over a Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-6"	Very dark brown (10YR 2/2) silt loam; weak fine granular structure; friable; abrupt boundary.
A3	6-18"	Very dark brown (10YR 2/2) silt loam; weak fine subangular blocky structure breaking to weak fine granular structure; friable; abrupt boundary.
B21	18-23"	Dark brown (10YR 3/2) silty clay loam; weak fine subangular blocky structure; friable; clear boundary.
B22	23-30"	Dark yellowish brown (10YR 4/4) silty clay loam; moderate medium subangular blocky structure; friable; abrupt boundary.
B3	30-41"	Yellowish brown (10YR 5/6) silty clay loam; weak fine subangular blocky structure; friable; abrupt boundary.
C1	41-96"	Olive (5Y 5/3) silt loam; few fine prominent strong brown (7.5YR 5/6) mottles; massive structure; friable; abrupt boundary.
C2	96-144"	Same as above but calcareous.
C3	144-303"	Yellowish brown (10YR 5/6) silt loam; common fine faint olive gray (5Y 5/2) relict mottles; massive structure; friable; abrupt boundary; calcareous.

C4	303-342"	Olive (5Y 5/3) silt loam; massive structure; friable; abrupt boundary; calcareous.
C5	342-390"	Dark yellowish brown (10YR 4/4) silt loam; massive structure; friable; abrupt boundary; calcareous.
C6	390-432"	Yellowish brown (10YR 5/6) silt loam; common fine faint olive gray (5Y 5/2) relict mottles; massive structure; friable; abrupt boundary; calcareous.
C7	432-478"	Olive gray (5Y 5/2) silt loam; few fine distinct dark yellowish brown (10YR 4/4) mottles; massive structure; friable to sticky; abrupt boundary; calcareous.
C8	478-516"	Greenish gray (5BG 5/1) silt loam; massive structure; sticky; abrupt boundary; calcareous.
Ab	516-521"	Black (5Y 2/2) silt loam; massive structure; abrupt boundry; organic carbon flecks indicate the basal soil of the Wisconsin loess.
Cb	521-528"	Dark greenish gray (5GY 4/1) silt loam; massive structure; sticky; abrupt boundary.
IIB21t	528-564"	Gray (5Y 5/1) clay loam; strong medium subangular blocky structure; firm; Sangamon paleosol.

SITE NO.: 4 SOIL SERIES: Monona

LOCATION: SW1/4 NW1/4 sec. 28, T.79N., R.38W., Shelby County, Iowa.

PARENT MATERIAL: 356 inches of Wisconsin loess over a Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-6"	Very dark brown (10YR 2/2) silt loam;weak fine granular structure; friable; abrupt boundary.
A3	6-22"	Black (10YR 2/1) silt loam; weak medium subangular blocky structure breaking to weak fine granular structure; friable; abrupt boundary.
B21	22-31"	Dark yellowish brown (10YR 3/4) silty clay loam; moderate medium subangular blocky structure; friable; clear boundary.
B22	31-42"	Dark yellowish brown (10YR 4/4) silty clay loam; moderate medium subangular blocky structure; friable; clear boundary.
B3	42-57"	Dark yellowish brown (10YR 4/4) silty clay loam; few fine distinct yellowish brown (10YR 5/6) mottles; moderate fine subangular blocky structure; friable; abrupt boundary.
C1	57-114"	Olive brown (2.5Y 4/4) silt loam; common fine prominent olive (5Y 5/3) and yellowish brown (10YR 5/6) mottles; weak fine subangular blocky structure; friable; abrupt boundary.
Fe-Mn	114-116"	Yellowish red (5YR 5/6) silt loam; moderate fine granular structure; firm; abrupt boundary.

C2	116-129"	Olive (5Y 5/3) silt loam; common fine prominent yellowish brown (10YR 5/6) mottles; massive structure; friable; abrupt boundary.
C3	129-151"	Same as above except calcareous.
Fe-Mn	151-152"	Yellowish red (5YR 5/6) silt loam; weak fine granular structure; firm to friable; abrupt boundary; calcareous.
C4	152-179"	Olive gray (5Y 5/2) silt loam; many medium prominent yellowish brown (10YR 5/6) mottles; massive structure; clear boundary; calcareous.
C5	179-236"	Grayish brown (2.5Y 5/2) silt loam; common fine distinct olive gray (5Y 5/2) mottles; massive structure; friable; calcareous.
C6	236-280"	Dark yellowish brown (10YR 4/4) silt loam; few fine distinct olive (5Y 5/3) mottles; massive structure; friable; clear boundary; calcareous.
C7	280-290"	Grayish brown (2.5Y 5/2) silt loam; common medium distinct yellowish brown (10YR 5/4) mottles; massive structure; friable; abrupt boundary; calcareous.
C8	290-305"	Brown to dark brown (7.5YR 4/4) silt loam; few fine distinct dark yellowish brown (10YR 4/4) mottles; massive structure; friable to sticky; abrupt boundary; calcareous.
C9	305-325"	Olive (5Y 5/3) silt loam; common medium prominent yellowish brown (10YR 5/6) mottles; massive structure; friable to sticky; clear boundary; calcareous.
C10	325-336"	Olive gray (5Y 5/2) silt loam; common medium prominent yellowish brown (10YR 5/6) mottles; massive structure; sticky; abrupt boundary.

Ab	336-345"	Dark grayish brown (10YR 4/2) silty clay loam; few fine prominent brown to dark brown (7.5YR 4/4) mottles; weak fine subangular blocky structure; sticky; abrupt boundary; organic carbon flecks indicate the basal soil of the Wisconsin loess.
Cb	345-356"	Olive gray (5Y 5/2) silt loam; common fine prominent yellowish red (5yR 5/6) mottles; massive structure; sticky; abrupt boundary.
IIA1	356-358"	Dark brown (7.5YR 3/2) silty clay loam; common fine distinct yellowish red (5YR 5/8) mottles; weak tc medium fine granular structure; friable to sticky; abrupt boundary; Sangamon paleosol.
IIA2	358-365"	Dark yellowish brown (10YR 3/4) silty clay loam; weak fine granular structure; friable; abrupt boundary.
IIB1t	365-373"	Brown to dark brown (10YR 4/3) clay loam; common medium distinct brown to dark brown (7.5YR 4/4) mottles; weak fine subangular blocky structure; firm to friable; abrupt boundary.
IIB21t	373-391"	Dark grayish brown (10YR 4/2) clay loam; common medium prominent strong brown (7.5YR 5/6) mottles; moderate medium subangular blocky structure; firm; abrupt boundary.
IIB22t	391-402"	Dark grayish brown (10YR 4/2) clay loam; common medium prominent dark reddish brown (5YR 3/4) mottles; strong medium subangular blocky structure; firm; abrupt boundary.

IIB23t	402-408"	Brown to dark brown (7.5YR 4/2) clay loam; medium subangular blocky structure; firm. many fine distinct reddish brown (5YR 4/4) mottles; moderate medium subangular blocky structure; firm.

SITE NO.: 5 SOIL SERIES: Minden

LOCATION: SE 1/4 NW1/4 sec. 24, T.87N., R.37W., Shelby County, Iowa.

PARENT MATERIAL: 288 inches of Wisconsin loess over a Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-6"	Black (10YR 2/1) silt loam; weak fine granular structure; friable; abrupt boundary.
A3	6-11"	Black (10YR 2/1) silt loam; weak fine subangular blocky structure breaking to weak fine granular structure; friable; clear boundary.
B21	11-15"	Very dark brown (10YR 2/2) silty clay loam; moderate fine subangular blocky structure; friable; clear boundary.
B22	15-24"	Very dark grayish brown (10YR 3/2) silty clay loam; moderate medium subangular blocky structure; friable; clear boundary.
B23	24-30"	Dark brown (10YR 3/3) silty clay loam; moderate medium subangular blocky structure; friable; clear boundary.
B3	30-43"	Dark yellowish brown (10YR 4/4) silty clay loam; weak medium subangular blocky structure; friable; clear boundary.
C1	43-87"	Olive gray (5Y 5/2) silt loam; common medium distinct yellowish brown (10YR 5/6) mottles; massive structure; friable; abrupt boundary.

C2	87-172"	Olive gray (5Y 5/2) silt loam; common medium distinct yellowish brown (10YR 5/6) mottles; massive structure; abrupt boundary; calcareous.
C3	172-227"	Brown to dark brown (10YR 4/3) silt loam; few faint black (5YR 2/1) Mn stains; massive structure; friable; abrupt boundary; calcareous.
C4	227-253"	Brown (10YR 5/3) silt loam; few faint black (5YR 2/1) Mn stains; massive structure; sticky; abrupt boundary.
C5	253-285"	Olive gray (5Y 5/2) silt loam; thin horizontal bands of oxides; many Fe-Mn concretions 1-2 mm in diameter; massive structure; sticky; abrupt boundary.
Ab	285-288"	Black (10YR 2/1) silt loam; massive structure; sticky; abrupt boundary; much organic carbon indicating the basal soil of the Wisconsin loess.
IIA1	288-292"	Very dark brown (10YR 2/2) silty clay loam; moderate fine granular structure; friable; clear boundary; Yarmouth-Sangamon paleosol.
IIA2	292-301"	Dark grayish brown (10YR 4/2) clay loam; moderate fine subangular blocky structure; firm; abrupt boundary.
IIB21t	301-315"	Very dark grayish brown (10YR 3/2) clay loam; strong medium subangular blocky structure; very firm.

SITE NO.: 6 SOIL SERIES: Sharpsburg

LOCATION: NW1/4 NE1/4 sec. 10, T.77N., R.33W., Adair County, Iowa.

PARENT MATERIAL: 197 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-6"	Very dark brown (10YR 2/2) silt loam; moderate fine granular structure; friable; abrupt boundary.
A12	6-10"	Very dark grayish brown (10YR 3/2) silt loam; moderate fine subangular blocky structure; friable; clear boundary.
A3	10-14"	Dark brown (10YR 3/3) silt loam; weak medium subangular blocky structure; friable; clear boundary.
B1	14-24"	Dark grayish brown (10YR 4/2) silt loam; weak medium subangular blocky structure; friable; clear boundary.
B21	24-32"	Brown to dark brown (10YR 4/3) silty clay loam; moderate medium subangular blocky structure; friable; clear boundary.
B22	32-42"	Dark yellowish brown (10YR 4/4) silty clay loam; few fine distinct yellowish brown (10YR 5/6) and grayish brown (2.5Y 5/2) mottles; strong medium subangular blocky structure; friable; clear boundary.
B23	42-48"	Dark yellowish brown (10YR 4/4) silt loam; common fine distinct yellowish brown (10YR 5/6) and grayish brown (2.5Y 5/2) mottles; medium fine subangular blocky structure; friable; clear boundary.

B3	48-54"	Light olive brown (2.5Y 5/4) silt loam; many medium prominent yellowish brown (10YR 5/6) and grayish brown (2.5Y 5/2) mottles; weak fine subangular blocky structure; friable; clear boundary.
C1	54-136"	Grayish brown (2.5Y 5/2) silt loam; many medium prominent yellowish brown (10YR 5/6) mottles; massive structure; friable; abrupt boundary.
C2	136-160"	Grayish brown (2.5Y 5/2) silt loam; many medium prominent yellowish brown (10YR 5/6) mottles; massive structure; friable; abrupt boundary; calcareous.
C3	160-192"	Grayish brown (2.5Y 5/2) silt loam; few fine prominent brown (7.5YR 5/4) mottles; massive structure; friable; abrupt boundary.
Ab	192-197"	Dark grayish brown (2.5Y 4/2) silt loam; massive structure; sticky; abrupt boundary; many organic carbon flecks indicate the basal soil of the Wisconsin loess.
IIB1	197-214"	Dark yellowish brown (10YR 4/4) silty clay loam; weak fine granular structure; firm; abrupt boundary; Yarmouth-Sangamon paleosol.
IIB21	214-240"	Olive brown (2.5Y 4/4) clay loam; few fine distinct dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/6) mottles; strong medium subangular blocky structure; firm.

SITE NO.: 7 SOIL SERIES: Macksburg

LOCATION: SW 1/4 SW 1/4 sec. 31, T.77N., R.30W., Adair County, Iowa.

PARENT MATERIAL: 164 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-6"	Black (10YR 2/1) silt loam; weak fine granular structure; friable; abrupt boundary.
A12	6-16"	Black (10YR 2/1) silt loam; weak fine subangular blocky structure; friable; clear boundary.
A3	16-22"	Very dark brown (10YR 2/2) silt loam; weak fine subangular blocky structure; friable; abrupt boundary.
B1	22-29"	Dark yellowish brown (10YR 3/4) silt loam; weak medium subangular blocky structure; friable; abrupt boundary.
B22	29-33"	Brown to dark brown (10YR 4/3) silty clay loam; few fine faint grayish brown (2.5Y 5/2) mottles; moderate medium subangular blocky structure; friable; abrupt boundary.
B23	33-46"	Grayish brown (2.5Y 5/2) silty clay loam; few medium prominent yellowish brown (10YR 5/6) mottles; weak medium subangular blocky structure; friable; clear boundary.
B3	46-60"	Grayish brown (2.5Y 5/2) silt loam; few medium prominent yellowish brown (10YR 5/6) mottles; weak fine subangular blocky structure; friable; clear boundary.

C1	60-109"	Grayish brown (2.5Y 5/2) silt loam; common medium prominent brown (7.5YR 5/4) mottles; massive structure; friable; abrupt boundary.
C2	109-142"	Grayish brown (2.5Y 5/2) silt loam; common medium prominent brown (7.5YR 5/4) mottles; massive structure; friable; abrupt boundary; calcareous.
C3	142-161"	Gray to light gray (2.5Y 6/0) silt loam; common medium prominent brown (7.5YR 5/4) mottles; massive structure; friable to sticky; abrupt boundary.
Ab	161-164"	Olive brown (2.5Y 4/4) silt loam; massive structure; sticky; abrupt boundary; many organic carbon flecks indicate the basal soil of the Wisconsin loess.
IIB2	164-168"	Dark yellowish brown (10YR 4/4) clay loam; strong medium subangular blocky structure; firm; Yarmouth-Sangamon paleosol.

SITE NO.: 8 SOIL SERIES: Sharpsburg

LCCATION: SW1/4 NW1/4 sec. 31, T.75N., R.29W., Madison County, Iowa.

PARENT MATEBIAL: 156 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-8"	Very dark brown (10YR 2/2) silt loam; weak fine granular structure; friable; abrupt boundary.
A3	8-18"	Very dark brown (10YR 2/2) silt loam; weak fine subangular blocky structure; friable; clear boundary.
B1	18-25"	Dark brown (10YR 3/3) silty clay loam; weak fine subangular blocky structure; friable; clear boundary.
B21t	25-34"	Brown to dark brown (10YR 4/3) silty clay loam; moderate medium subangular blocky structure; friable; clear boundary.
B22t	34-46"	Dark grayish brown (10YR 4/2) silty clay loam; few medium distinct yellowish brown (10YR 5/6) mottles; strong medium subangualr blocky structure; firm; clear boundary.
B3	46-59"	Dark grayish brown (2.5Y 4/2) silty clay loam; common medium distinct yellowish brown (10YR 5/6) mottles; moderate medium subangular blocky structure; firm; abrupt boundary.
C1	59-83"	Olive (5Y 5/3) silty clay loam; common medium prominent yellowish red (5YR 4/6) mottles; massive structure; friable; abrupt boundary.

C2	83-125"	Olive gray (5Y 5/2) silty clay loam; few medium prominent black (5YR 2/1) mottles and many fine prominent reddish brown (5YR 4/6) mottles; massive structure; friable to sticky; abrupt boundary.
Fe-Mn	125-133"	Olive (5Y 5/2) silt loam; many coarse prominent reddish brown (5YR 4/6) iron oxide concretions; massive structure; friable to sticky; abrupt boundary.
C3	133-150"	Olive gray (5Y 5/2) silt loam; many medium prominent reddish brown (5YR 4/6) mottles; massive structure; friable to sticky; abrupt boundary.
Ab	150-156"	Very dark grayish brown (10YR 3/2) silty clay loam; massive structure; sticky; abrupt boundary; many organic carbon flecks indicate the basal soil of the Wisconsin loess.
IIB1	156-164"	Olive gray (5Y 5/2) clay loam; moderate medium subangular blocky structure; firm; abrupt boundary; Yarmouth-Sangamon paleosol.
IIB21t	164-180"	Dark grayish brown (2.5Y 4/2) clay loam; many fine distinct yellowish brown (10YR 5/6) mottles; moderate medium subangular blocky structure; firm; abrupt boundary.
IIB22t	180-220"	Olive gray (5Y 5/2) clay loam; many medium distinct light olive brown (2.5Y 5/6) mottles and prominent yellowish red (5YR 5/6) mottles; strong medium subangular blocky structure; firm.

SITE NO.: 9 SOIL SERIES: Winterset

LOCATION: NE1/4 SW1/4 sec. 4, T.73N., R.38W., Union County, Iowa.

PARENT MATERIAL: 140 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-6"	Black (10YR 2/1) silt loam; weak fine granular structure; friable; abrupt boundary.
A12	6-12"	Black (10YR 2/1) silt loam; weak medium granular structure; friable; clear boundary.
A3	12-22"	Very dark brown (10YR 2/2) silty clay loam; weak medium subangular blocky structure; friable; abrupt boundary.
B21	22-28"	Dark grayish brown (2.5Y 4/2) silty clay loam; common fine distinct yellowish brown (10YR 5/4) mottles; weak medium subangular blocky structure; friable; clear boundary.
B22	28-36"	Grayish brown (2.5Y 5/2) silty clay loam; common medium prominent yellowish brown (10YR 5/6) mottles; moderate medium subangular blocky structure; friable; clear boundary.
B23	36-52"	Grayish brown (2.5Y 5/2) silty clay loam; common medium prominent yellowish brown (10YR 5/6) mottles; weak fine subangular blocky structure; friable; clear boundary.
B3	52-60"	Light brownish gray (2.5Y 6/2) silt loam; common medium prominent brown (7.5YR 5/4) mottles; weak fine subangular blocky structure; friable; clear boundary.

C1	60-94"	Gray (2.5Y 6/0) silt loam; common fine prominent strong brown (7.5YR 5/6) mottles; massive structure; friable; abrupt boundary.
C2	94-136"	Light olive brown (2.5Y 5/4) silt loam; many fine prominent yellowish brown (10YR 5/4) mottles; massive structure; friable; abrupt boundary.
Ab	136-140"	Very dark grayish brown (10YR 3/2) silt loam; massive structure; sticky; abrupt boundary; presence of organic carbon flecks indicates the basal soil of the Wisconsin loess.
IIB21	140-152"	Dark grayish brown (2.5Y 4/2) clay loam; few fine distinct dark yellowish brown (10YR 4/4) mottles; moderate fine subangular blocky structure; firm; abrupt boundary; Yarmouth-Sangamon paleosol.
IIB22	152-168"	Very dark grayish brown (2.5Y 3/2) clay loam; common fine prominent brown (7.5YR 5/4) mottles; strong medium subangular blocky structure; firm.

SITE NO.: 10 SOIL SERIES: Haig

LOCATION: SE1/4 NW1/4 sec. 12, T.71N., R.26W., Clarke County, Iowa.

PARENT MATERIAL: 102 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-8"	Black (10YR 2/1) silt loam; weak fine granular structure; friable; abrupt boundary.
A3	8-17"	Black (10YR 2/1) light silty clay loam; moderate fine subangular blocky structure; friable; abrupt boundary.
B1t	17-24"	Very dark grayish brown (10YR 3/2) silty clay loam; many fine distinct dark brown (10YR 2/2) mottles; moderate fine subangular blocky structure; friable; abrupt boundary.
B21t	24-30"	Very dark gray (10YR 3/1) silty clay loam; common fine distinct yellowish brown (10YR 4/4) mottles; moderate medium subangular blocky structure; firm; abrupt boundary.
B22t	30-42"	Very dark gray (10YR 3/1) clay loam; common fine distinct dark yellowish brown (10YR 4/4) mottles; strong coarse subangular blocky structure; firm; abrupt boundary.
B23t	42-48"	Olive gray (5Y 4/2) clay loam; common medium distinct yellowish brown (10YR 5/6) mottles; strong medium subangular blocky structure; firm; abrupt boundary.

B3	48-56"	Olive gray (5Y 4/2) silty clay loam; common medium prominent strong brown (7.5YR 5/6) mottles; weak medium subangular blocky structure; abrupt boundary.
C1	56-63"	Olive gray (5Y 5/2) silty clay loam; many coarse prominent strong brown (7.5YR 5/6) mottles; massive structure; friable to sticky; abrupt boundary.
Fe-Mn	63-65"	Yellowish red (5YR 5/8) silt loam; moderate fine granular structure; firm; abrupt boundary.
C2	65-96"	Olive gray (5Y 5/6) silty clay loam; common fine prominent dark yellowish brown (10YR 4/4) mottles and few fine faint blueish gray (5BG 5/1) mottles below 88 inches; massive structure; sticky; abrupt boundary.
Ab	96-102"	Dark gray (5Y 4/1) silty clay loam; weak fine granular to massive structure; sticky; abrupt boundary; presence of organic carbon flecks indicates the basal soil of the Wisconsin loess.
IIB21t	102-131"	Gray (5Y 5/1) clay loam; common medium prominent yellowish red (5YR 4/6) mottles; strong medium subangular blocky structure; firm; abrupt boundary; Yarmouth-Sangamon paleosol.
IIB22t	131-144"	Olive (5Y 5/3) clay loam; common fine prominent yellowish red (5YR 5/8) mottles; strong medium subangular blocky structure; very firm.

SITE NO.: 11 SOIL SERIES: Haig

LOCATION: SE1/4 NE1/4 sec. 15, T.70N., R.24W., Decatur County, Iowa.

PARENT MATERIAL: 106 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-7"	Very dark brown (10YR 2/2) silty clay loam; weak fine granular structure; friable; abrupt boundary.
A3	7-16"	Black (10YR 2/1) silty clay loam; weak fine subangular blocky structure; friable; abrupt bolndary.
B1t	16-21"	Very dark grayish brown (10YR 3/2) silty clay loam; few fine faint dark yellowish brown (10YR 4/4) mottles; moderate medium subangular blocky structure; firm; abrupt boundary.
B21t	21-28"	Very dark gray (10YR 3/1) silty clay loam; common fine distinct dark yellowish brown (10YR 4/4) mottles; strong medium subangular blocky structure; firm; abrupt boundary.
B22t	28-34"	Dark gray (2.5Y 4/1) light clay loam; common medium distinct brown to dark brown (7.5YR 4/4) mottles; strong medium subangular blocky structure; firm; abrupt boundary.
B23t	34-48"	Olive gray (5Y 5/2) silty clay loam; common medium prominent brown to dark brown (7.5YR 4/4) mottles; weak medium subangular blocky structure; very firm; abrupt boundary.

B3	48-58"	Olive gray (5y 5/2) light silty clay loam; common medium dictinct brown to dark brown (7.5YR 4/4) mottles; weak fine subangular blocky structure; firm to sticky; abrupt boundary.
Fe-Mn	58-65"	Strong brown (7.5YR 5/6) silt loam; weak fine granular structure; firm; abrupt boundary.
C	65-102"	Gray (5Y 5/1) silty clay loam; few medium prominent brown to dark brown (7.5YR 4/4) mottles; massive structure; sticky; abrupt boundary.
Ab	102-106"	Very dark gray (10YR 3/1) silty clay loam; massive structure; sticky; abrupt boundary; presence of many organic carbon flecks indicates the basal soil of the Wisconsin loess.
IIB21t	106-120"	Dark gray (10YR 4/1) clay loam; few fine faint gray (10YR 5/1) mottles; very strong medium subangular blocky structure; very firm; Yarmouth-Sangamon paleosol.

SITE NO.: 12 SOIL SERIES: Edina

LOCATION: SW1/4 NW1/4 sec. 25, T.69N., R.23W., Wayne County, Iowa.

PARENT MATERIAL: 96 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-8"	Very dark brown (10YR 2/2) silty clay loam; weak fine granular structure; friable; abrupt boundary.
A2	8-16"	Dark grayish brown (10YR 4/2) silty clay loam; weak fine platy structure breaking to weak fine angular blocky structure; friable; abrupt boundary.
B21t	16-21"	Very dark grayish brown (10YR 3/2) silty clay loam; weak fine subangular blocky structure; friable; abrupt boundary.
B22t	21-29"	Very dark gray (10YR 3/1) clay loam;many fine distinct dark yellowish brown (10YR 4/4) mottles; strong medium subangular blocky structure; firm to sticky; abrupt boundary.
B23t	29-39"	Very dark grayish brown (10YR 3/2) clay loam; many medium distinct dark yellowish brown (10YR 4/4) mottles; moderate medium subangular blocky structure; firm to sticky; abrupt boundary.
B3	39-49"	Dark grayish brown (2.5Y 4/2) silty clay loam; common medium prominent yellowish brown (10YR 5/6) mottles; moderate medium subangular blocky structure; firm to sticky; abrupt boundary.

C	49-90"	Grayish brown (2.5Y 5/2) silty clay loam; many medium distinct yellowish red (5YR 4/6) mottles; massive structure; sticky; abrupt boundary.
Ab	90-96"	Olive gray (5Y 5/2) silty clay loam; massive structure; sticky; one thin band of gray (5Y 3/1) organic carbon and many organic carbon flecks indicate the basal soil of the Wisconsin loess.
IIB21t	96-139"	Dark gray (5Y 4/1) clay loam; common medium prominent gray (10YR 5/1) mottles; strong medium subangular blocky structure; very firm; Yarmouth-Sangamon paleosol.

SITE NO.: 13 SOIL SERIES: Edina

LOCATION: SW1/4 NE1/4 sec. 3, T.67N., R.21W., Wayne County, Iowa.

PARENT MATERIAL: 79 inches of Wisconsin loess over a Yarmouth-Sangamon paleosol.

HORIZON	DEPTH	DESCRIPTION
Ap	0-8"	Very dark brown (10YR 2/2) silt loam; weak fine granular structure; friable; abrupt boundary.
A2	8-16"	Grayish brown (10YR 5/2) silt loam; weak fine platy structure breaking to weak fine angular to subangular blocky structure; friable; abrupt boundary.
B21t	16-21"	Very dark gray (10YR 3/1) silty clay loam; common fine distinct dark yellowish brown (10YR 4/4) mottles; moderate medium subangular blocky structure; firm; abrupt boundary.
B22t	21-30"	Dark grayish brown (2.5Y 4/2) clay loam; common fine distinct dark yellowish brown (10YR 4/4) mottles; strong medium subangular blocky structure; firm; abrupt boundary.
B23t	30-44"	Olive gray (5Y 4/2) silty clay loam; common medium distinct dark yellowish brown (10YR 4/4) mottles; weak fine subangular blocky structure; firm; abrupt boundary.
B3	44-65"	Olive gray (5Y 5/2) silty clay loam; few medium prominent brown to dark brown (7.5YR 4/4) mottles; very weak fine angular blocky structure; firm; abrupt boundary.
Fe-Mn	65-68"	Yellowish red (5YR 5/6) silt loam; medium fine angular blocky structure; firm; abrupt boundary.

C	68-72"	Olive gray (5Y 5/2) silty clay loam; few fine prominent yellowish red (5YR 5/6) mottles; massive structure; very sticky; abrupt boundary.
Ab	72-79"	Dark grayish brown (10YR 4/2) silt loam; weak fine granular structure; very sticky; abrupt boundary; presence of organic carbon flecks indicates the basal soil of the Wisconsin loess.
IIB21t	79-94"	Grayish brown (2.5Y 5/2) clay loam; common medium distinct dark yellowish brown (10YR 4/4) mottles; strong medium subangular blocky structure; very firm; Yarmouth-Sangamon paleosol.

APPENDIX C

CATALOQUE OF RADIOCARBON DATES

The format followed is that of Radiocarbon, published annually by the American Journal of Science at Yale University. I samples were dated by Isotopes Incorporated, Englewood Cliffs, New Jersey, and W samples by U. S. Geological Survey, Washington, D. C.

I 1023 Bently, Pottawattamie County 21,360 ± 850

Spruce wood from organic zone of base of Wisconsin loess in cut along Rock Island Railroad in NW1/4 sec. 21, T.76N., R.41W. (41°22'N, 95°35'W). Section from surface downward is leached loess, 8 feet; calcareous loess, 29 feet; leached loess, 6 feet; organic zone in base of loess, 3 feet; Sangamon paleosol, 4 feet. Sampled from depth of 43 to 44 feet. Collected by R. V. Ruhe, 1961, and submitted, 1963.

I 1408 Harvard, Wayne County 19,200 ± 900

Organic carbon from base of Wisconsin loess in NW1/4 sec. 15, T.68N., R.21W. (40°42'N,93°16'W). Core from surface downward was leached Wisconsin loess, 8.3 feet; Yarmouth-Sangamon paleosol, 2+ feet. Sample from depth of 7.6 to 8.3 feet. Collected by W. P. Dietz and J. P. Highland, 1964; submitted by R. V. Ruhe, 1965.

I 1410 Murray, Clarke County 20,900 ± 1000

Organic carbon from base of Wisconsin loess in NW104 SW74 sec.W.10 T.72N., R.27W.(41°2'N,93°57'W). Core from surface downward was leached Wisconsin loess 11 feet; Yarmouth-Sangamon paleosol, 14 feet. Sample from depth of 10.3 to 11 feet. Collected by W. H. Dietz and J. D. Highland, 1964; submitted by R. V. Ruhe, 1965.

I 1411 Greenfield, Adair County 18,700 ± 700

Organic carbon from base of Wisconsin loess of WC sec.17, T.70N., R.31W.(41°22'N,94°27'W). Core from surface downward was leached Wisconsin loess, 15 feet; Yarmouth-Sangamon paleosol. Sample from depth of 14.3 to 15 feet. Collected by W. P. Dietz, J. D. Highland, T. E. Fenton and R. V. Ruhe, 1964; submitted by R. V. Ruhe, 1965.

I 1419A Humeston, Wayne County 16,500 ± 500

Organic carbon from base of Wisconsin loess in SE1/4 sec.21, T.69N., R.23W. (40°45'N, 93°31'W). Core from surface downward was leached Wisconsin loess, 9.25 feet; Yarmouth-Sangamon paleosol. Sample from depth of 8.5 to 9.25 feet. Collected by W. P. Dietz, J. D. Highland; T. E. Fenton and R. V. Ruhe, 1964; submitted by R. V. Ruhe, 1965.

I 1420 Bentley, Pottawattamie County 23,900 ± 1,100

Organic carbon from buried soil A horizon at base of Wisconsin contained spruce wood. Cf. I-1023 for section description. Reasonable agreement between soil organic carbon and wood indicates validity of buried soil organic carbon as dating medium. Collected by R. V. Ruhe, 1964, and submitted, 1965.

I 3702 Adair, Adair County 21,150 ± 450

Organic carbon from base of Wisconsin loess on Mississippi - Missouri Divide in NE1/4 sec.11, T.77N., R.33W. (41°30'N, 94°42'W). Core from surface downward was leached Wisconsin loess, 11.5 feet; calcareous loess, 1.8 feet; leached loess, 3.0 feet; leached loess with organic carbon, 1.3 feet; Yarmouth-Sangamon paleosol in Kansan till, 4.3 feet. Sample from depth of 16.0 to 16.5 feet. Collected by B. K. Worcester, 1968; submitted by R. V. Ruhe, 1968.

I 3703 Persia, Harrison County 19,250 ± 400

Organic carbon from organic layer in Wisconsin loess 3.0 feet above base of loess on topographic divide in SE1/4 sec.12, T.79N., R.41W.(41°90'N, 95°33'W). Core from surface downward was leached Wisconsin loess, 4.8 feet; calcareous loess, 37.2 feet; leached loess, 5.0 feet; leached Sangamon paleosol on Loveland loess, 2+ feet. Sample from depth of 43.7 to 44.3 feet. Collected by E. K. Worcester, 1968; submitted by R. V. Ruhe, 1968.

I 3943 Hancock 2, Pottawattamie County 22,200 ± 500

Organic carbon from upper half of organic zone in base of Wisconsin loess in cut 33 along Rock Island Railroad in NC NE1/4 sec.23,T.76N., R.40W. (40°21'N, 95°25'N). Section from surface downward was leached loess, 9.7 feet; calcareous loess, 15.4 feet; leached loess, 1.9 feet; leached organic zone 1.3 feet; A1b horizon of Sangamon paleosol, 0.5 feet; subjacent Sangamon paleosol in Loveland loess, 7+ feet. Sample from depth of 27.0 to 27.6 feet. Sample and submitted by R. V. Ruhe, 1968. Cf. I-3944, I-3945, W-141.

I 3944 Hancock 2, Pottawattamie County 22,750 ± 600

Organic carbon from lower half of organic zone in base of Wisconsin loess in cut 33. Cf. I-3943, I-3945, W-141. Sample from depth of 27.6 to 28.2 feet.

I 3945 Hancock 2, Pottawattamie County 23,200 ± 600

Organic carbon from A1b horizon of Sangamon paleosol in cut 33. Cf. I-3944, I-3944, W-141. Sample from depth of 28.2 to 28.7 feet.

I 4211 Lincoln Township 2, Harrison Co. 22,350 ± 700

Organic carbon from dark colored band in Wisconsin loess in north road cut along south line of SW1/4 sec.9, T.81N. (41°50'N, 95°45'W). Section from surface downward is calcareous loess, 11.5 feet; upper dark band, 0.5 feet; calcareous loess, 17.5 feet; lower dark band, 0.5 feet; calcareous loess, 1.5 feet in cut; in boring at base of cut; calcareous loess 4.5 feet; leached loess, 7.8 feet; basal leached organic zone, 2.4 feet; leached Sangamon paleosol, 2+ feet. Sample depth 29.5 to 30.0 feet. Collected by W. H. Boyd, H. J. Kleiss and R. V. Ruhe, 1969; submitted by R. V. Ruhe, 1969.

I 5107 Pisgah, Harrison County 23,300 ± 550

Organic carbon and charcoal flecks from base of Wisconsin loess. Located in scuth corner of SW1/4 sec.8, T.81N., R.44W. Sample located in vertical face near top of bluff 100 feet above grade of county road D (see Ruhe, R. V. 1949. A Bignell(?) loess section in western Iowa, Iowa Acadamy of Science. 56: 229-231.). Collected by B. K. Worcester, G. A. Miller and R. V. Ruhe, 1970; submitted by R. V. Ruhe, 1970.

I 5527 Elk Horn, Shelby County

Organic carbon from base of Wisconsin loess in SE1/4NW1/4 sec.24, T.78N., R.37W. (41°32'N, 95°2'W). Core from surface downward was leached loess, 7.3 feet; calcareous loess, 11.7 feet; leached loess, 4.9 feet; leached loess with organic carbon, 0.5 feet; Yarmouth-Sangamon paleosol in Kansan till, 2+ feet. Sample from depth of 23.9 to 24.5 feet. Collected by B. K. Worcester, 1970; submitted by W. H. Scholtes, 1970.

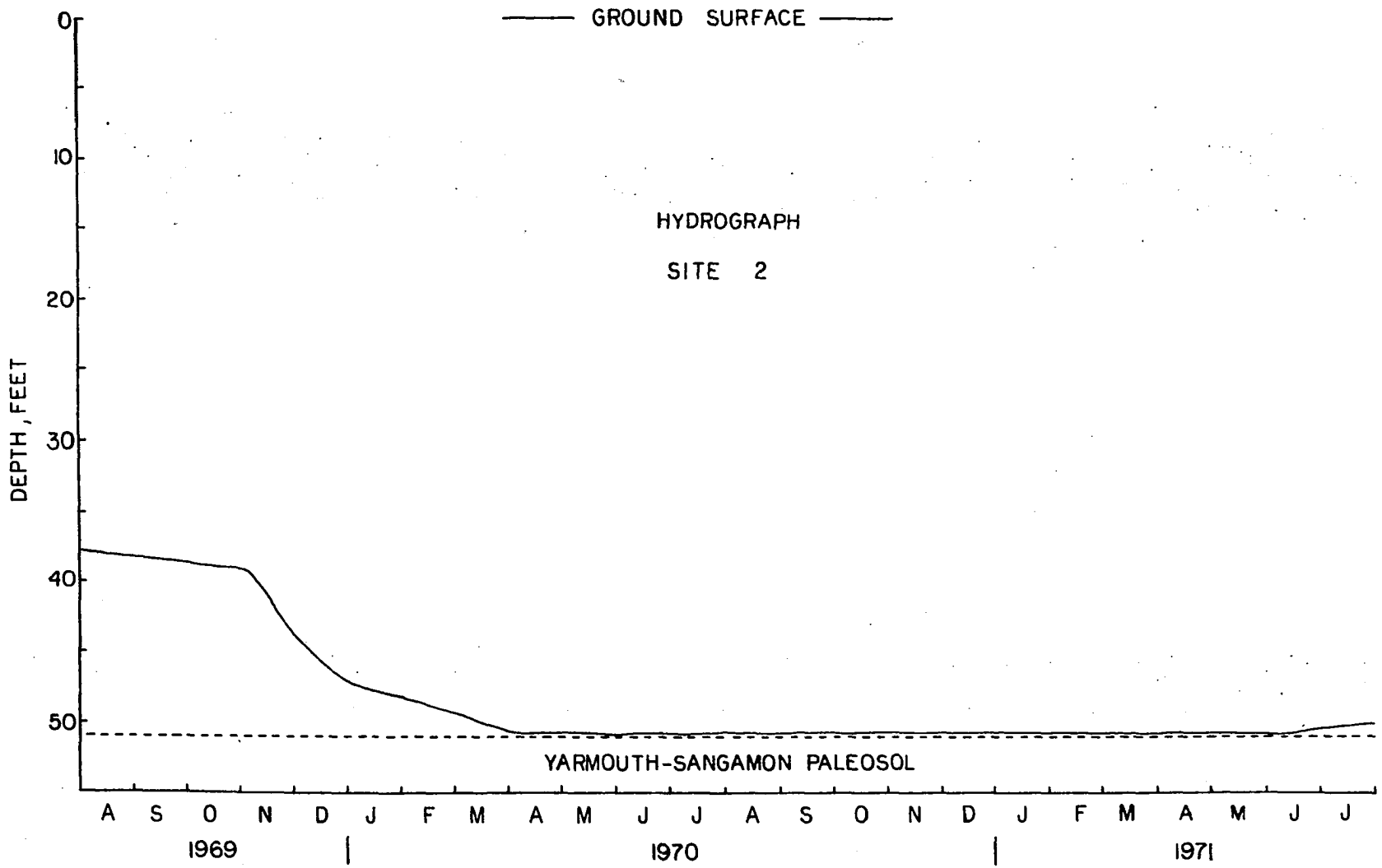
W 141 Hancock, Pottawattamie County 24,500 ± 800

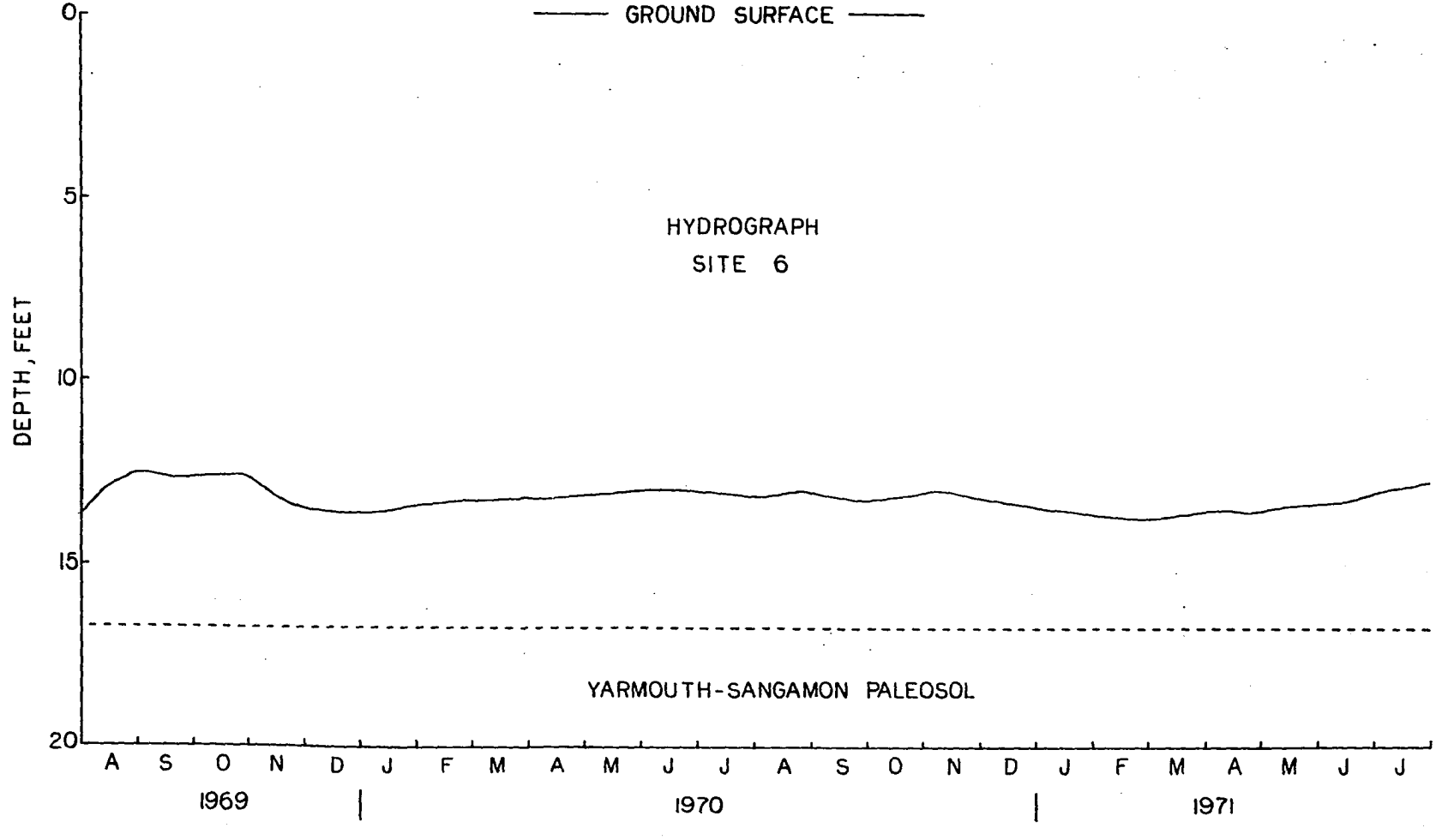
Larch wood from peat at base of Wisconsin loess in south cut along Rock Island Railroad in NC NE1/4 sec. 23, T.76N., R.40W. (41°21'N, 95°25' W). Section from surface downward was leached loess, 9.7 feet; calcareous loess, 18.3 feet; leached loess, 1.9 feet; peat, 1.3 feet;, 5+ feet. Sample from depth of 30 to 31 feet. Collected and submitted by R. V. Ruhe, 1964.

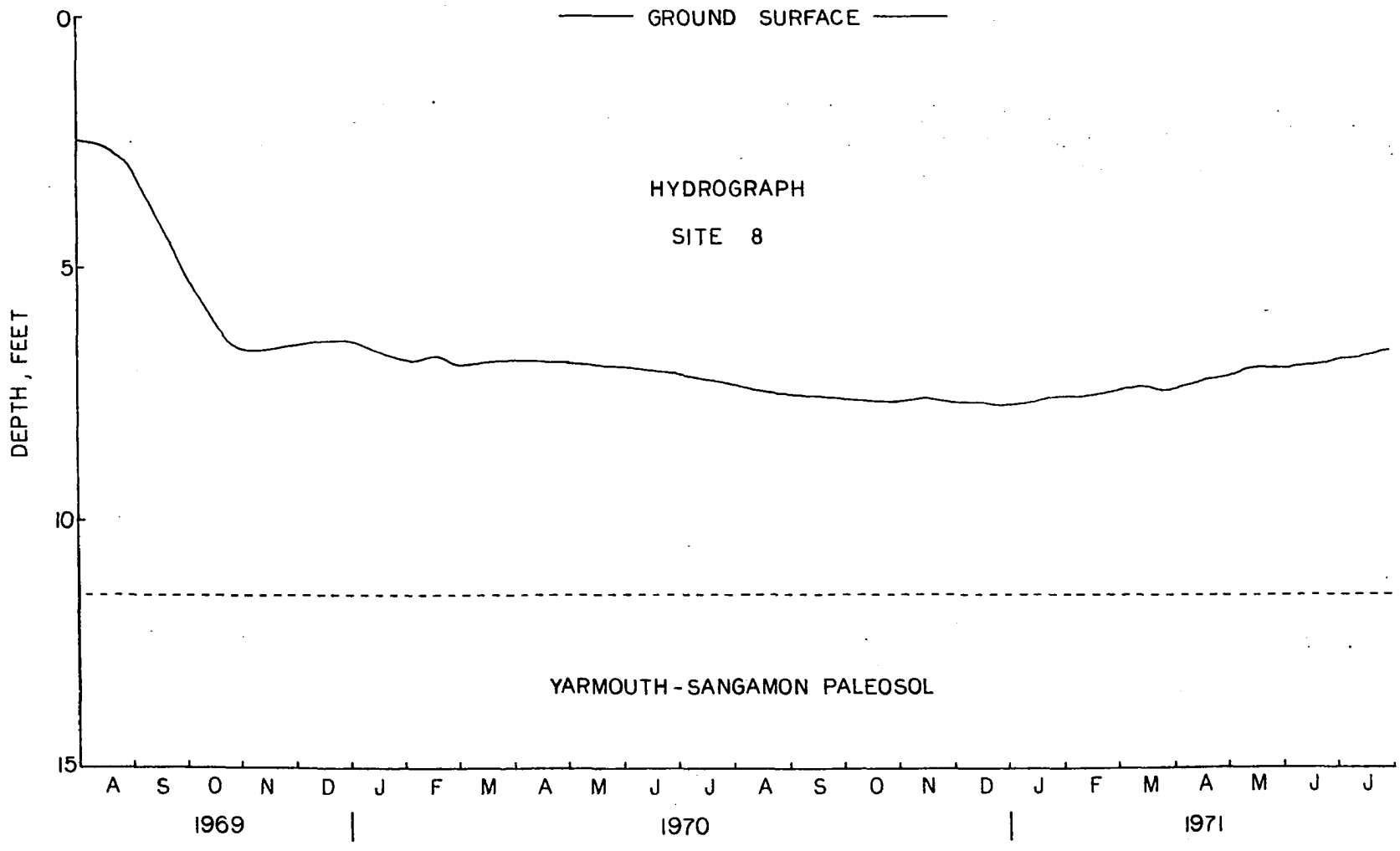
APPENDIX D

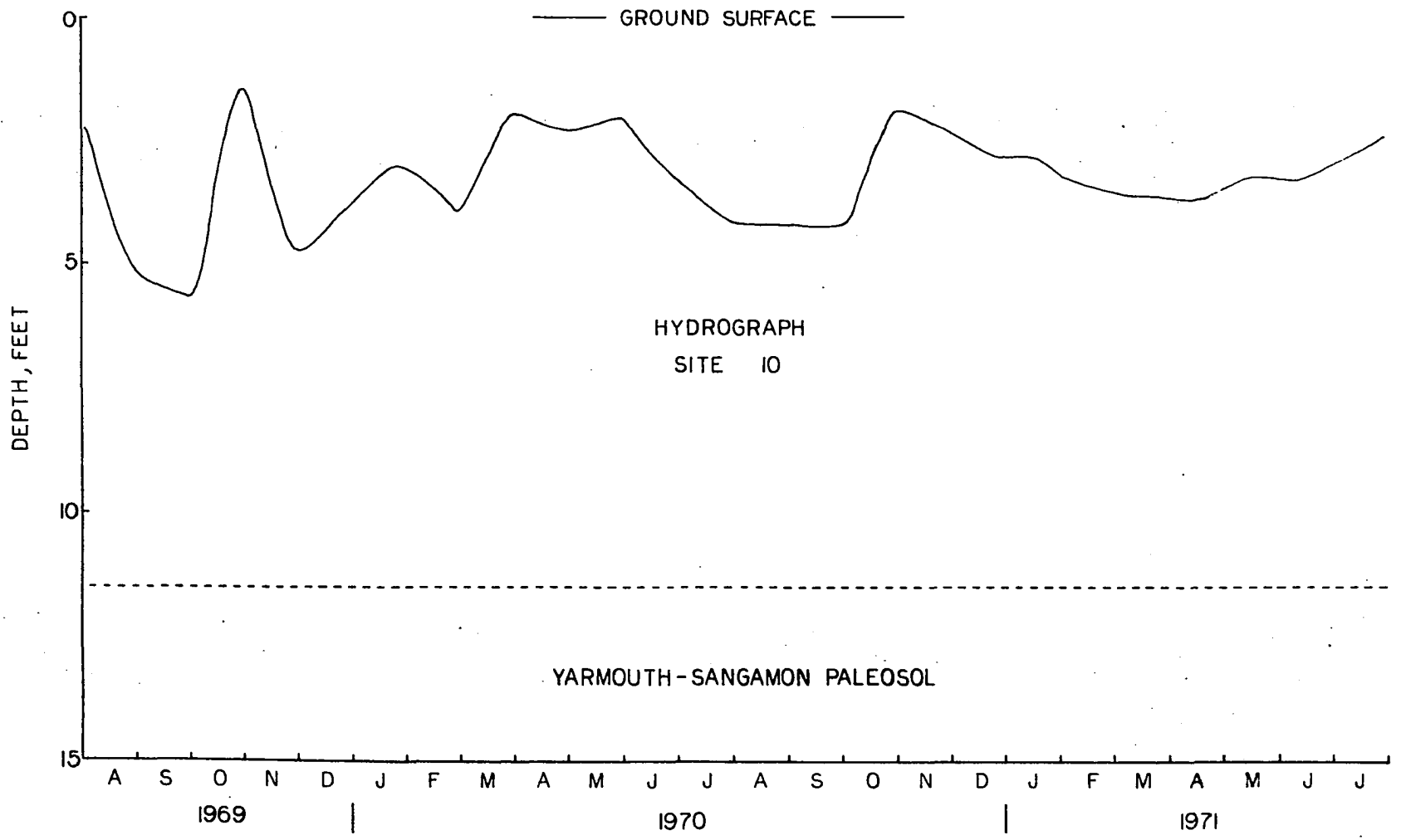
PERCHED WATER-TABLE HYDROGRAPHS

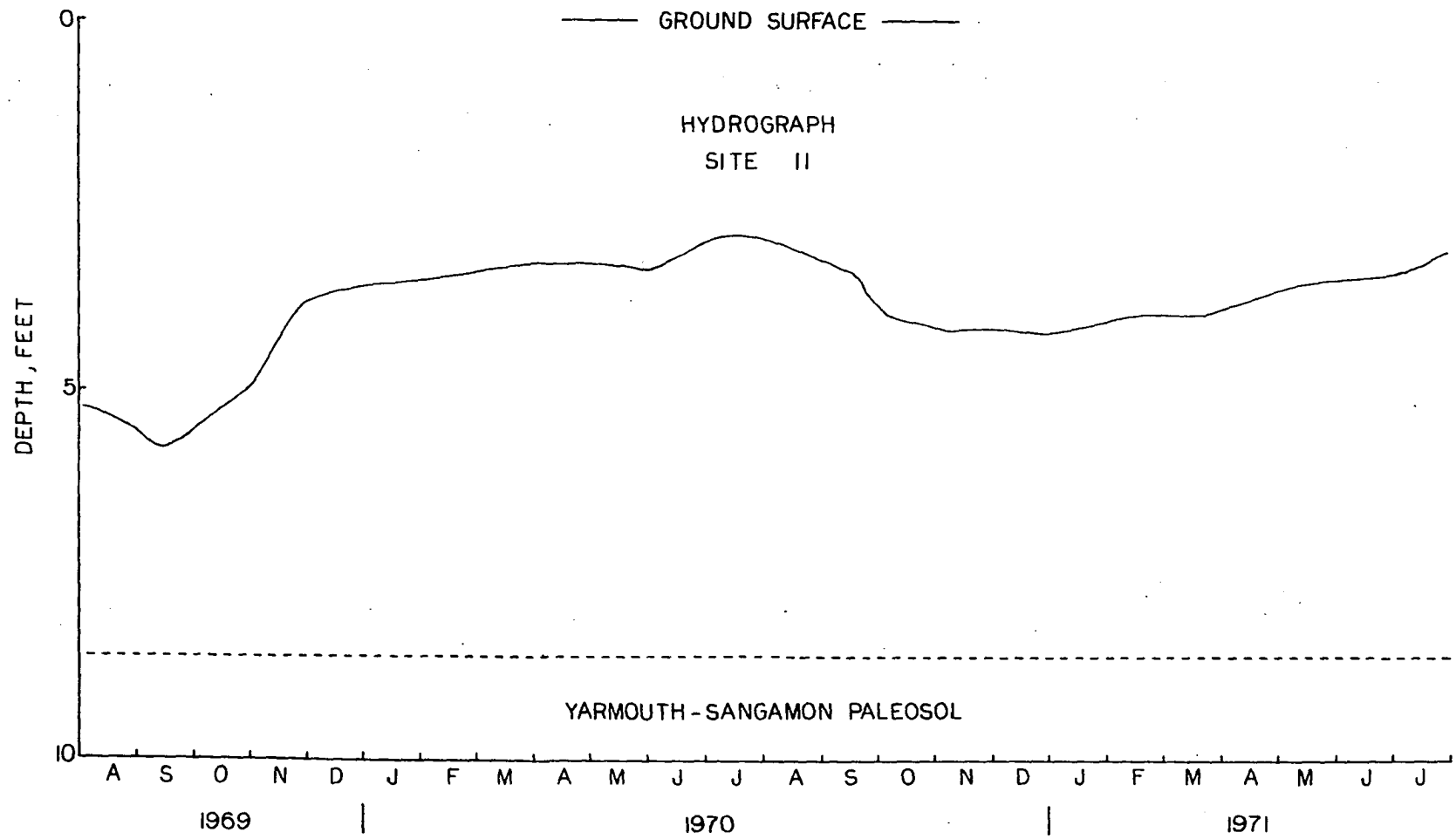
Hydrographs of the ground-water wells at research sites 2, 6, 8, 10, 11.


GROUND SURFACE
HYDROGRAPH
SITE 2
DEPTH, FEET
0
10
20
30
40
50
YARMOUTH-SANGAMON PALEOSOL
A S O N D J F M A M J J A S O N D J F M A M J J
1969
1970
1971


GROUND SURFACE
HYDROGRAPH
SITE 6
DEPTH, FEET
0
5
10
15
20
YARMOUTH-SANGAMON PALEOSOL
A S O N D J F M A M J J A S O N D J F M A M J J
1969
1970
1971


GROUND SURFACE
HYDROGRAPH
SITE 8
DEPTH, FEET
0
5
10
15
YARMOUTH - SANGAMON PALEOSOL
A S O N D J F M A M J J A S O N D J F M A M J J
1969
1970
1971


GROUND SURFACE
0
5
10
15
DEPTH, FEET
HYDROGRAPH
SITE 10
YARMOUTH-SANGAMON PALEOSOL
A S O N D J F M A M J J A S O N D J F M A M J J
1969
1970
1971


GROUND SURFACE
HYDROGRAPH
SITE II
DEPTH, FEET
0
5
10
YARMOUTH - SANGAMON PALEOSOL
A S O N D J F M A M J J A S O N D J F M A M J J
1969
1970
1971

APPENDIX E:

PARTICLE SIZE ANALYSIS DATA

Tables of particle size analysis data. All determinations were run on the Wentworth scale of size fractions and are reported in microns.

SITE 2

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 5	0.64	23.05	29.95	11.74	4.68	3.20	2.30	16.24	8.20
5- 10	0.53	0.0	29.25	12.28	4.42	3.46	0.0	0.0	0.0
10- 15	0.58	20.98	28.46	12.92	4.74	3.34	2.62	15.24	11.12
15- 20	0.46	20.90	27.36	13.72	5.54	3.78	2.86	15.10	10.28
20- 25	0.49	19.03	27.94	14.24	5.32	4.28	2.52	15.74	10.44
25- 30	0.59	20.77	28.36	12.80	5.38	4.04	2.28	15.48	10.30
30- 36	0.90	20.35	31.22	13.16	5.06	3.36	3.42	13.56	8.98
48- 52	0.74	21.16	30.66	13.44	5.58	3.16	3.64	13.92	7.70
52- 55	1.00	23.32	30.70	12.18	5.10	2.92	3.54	13.34	7.90
55- 60	0.96	23.89	32.49	10.86	4.44	3.04	3.52	14.66	6.14
60- 65	0.79	23.29	32.61	11.36	4.44	3.00	3.56	14.24	6.72
65- 70	1.27	23.30	28.21	11.44	5.28	3.70	4.22	15.52	7.06
70- 75	1.23	25.77	31.08	12.26	4.52	2.70	3.46	13.40	5.58
75- 80	0.94	23.69	33.25	12.76	4.58	2.80	3.70	13.08	5.20
80- 85	0.84	0.0	38.31	0.0	5.00	3.24	3.90	13.78	5.78
85- 90	0.94	24.00	32.02	13.34	5.08	3.06	3.70	14.04	3.82
90- 95	1.32	26.26	30.92	13.12	5.50	3.56	2.12	13.76	3.44
95-100	1.42	26.53	32.15	13.26	5.02	3.42	3.84	11.76	2.60
100-105	1.34	26.57	33.99	14.10	5.20	3.56	1.82	7.16	6.26
105-110	1.23	24.15	36.65	14.86	5.02	2.84	3.66	10.02	1.58
110-115	1.26	23.99	33.27	14.56	5.48	3.18	4.04	11.74	2.48
115-120	1.30	24.57	33.93	13.40	5.12	3.36	3.94	11.82	2.56
120-125	1.44	27.23	33.03	13.10	5.06	3.20	4.02	10.84	2.08
130-135	1.19	25.07	33.23	11.88	5.58	3.88	4.28	12.16	2.74
140-145	1.21	29.43	30.02	12.88	4.40	3.18	3.90	11.62	2.76
150-155	1.34	24.61	35.81	13.20	4.70	3.10	3.68	10.74	2.82
160-165	1.50	26.43	32.77	12.44	4.82	3.26	3.58	11.88	3.62
170-175	1.77	22.83	29.24	13.92	6.82	4.26	4.10	13.12	3.94

SITE 2 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
180-185	1.24	22.78	34.85	13.68	5.28	3.30	3.16	11.84	3.88
190-195	0.84	27.29	32.37	12.02	5.08	3.44	3.22	12.06	3.68
200-205	0.41	27.18	32.13	11.78	5.06	3.16	3.48	12.46	4.34
210-215	0.96	23.03	33.43	13.50	5.46	3.44	3.56	12.86	3.76
220-225	1.01	22.02	33.01	14.90	6.04	3.56	3.28	12.30	3.88
230-235	0.95	23.37	33.97	12.88	5.08	3.44	3.42	12.48	4.42
240-245	0.79	21.48	33.59	14.04	5.82	3.60	3.58	12.42	4.68
250-255	0.73	22.59	33.43	14.04	5.50	3.50	3.52	12.56	4.14
260-265	1.35	28.34	33.23	10.80	4.44	2.92	3.08	11.68	4.16
270-275	1.38	26.95	32.59	10.90	5.26	3.48	3.06	12.48	3.90
280-285	0.79	27.88	33.45	10.84	4.68	2.76	2.82	12.06	4.72
290-295	0.78	26.11	34.87	12.48	4.94	2.72	2.82	11.38	3.90
300-305	0.62	25.46	33.19	11.02	6.68	2.78	2.52	11.04	4.70
310-315	0.27	23.10	34.65	12.82	5.72	3.00	2.96	11.92	5.56
320-325	0.30	25.21	35.87	11.48	4.82	2.62	2.96	11.88	4.86
330-335	0.26	23.81	34.27	12.52	5.18	2.92	1.96	12.86	6.22
340-345	0.69	21.08	34.09	14.64	5.62	3.16	3.24	12.04	5.44
350-355	0.42	24.69	34.17	12.12	5.06	2.86	2.98	11.96	5.74
360-365	0.96	30.85	36.55	12.00	4.26	3.34	2.62	6.86	2.26
370-375	0.0	0.0	35.03	12.40	4.92	3.48	3.34	8.20	2.32
380-385	0.65	27.80	34.81	13.80	5.10	4.96	2.42	7.70	2.76
390-395	0.76	29.77	36.11	12.46	4.46	3.48	3.28	7.08	2.68
400-405	0.66	26.06	38.59	14.18	4.72	3.52	3.60	6.38	2.30
410-415	0.74	27.99	37.31	12.74	4.60	3.72	3.36	7.20	2.34
420-425	0.65	26.83	34.17	13.62	5.34	4.10	3.74	8.36	3.20
430-435	0.54	22.77	34.33	14.12	5.90	4.38	4.68	11.02	2.26
440-445	0.65	24.54	38.35	15.48	5.10	4.02	3.68	7.40	0.0
450-455	0.76	28.35	36.85	12.76	4.38	3.38	3.16	7.62	2.74

SITE 2 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
455-460	0.57	27.06	36.47	13.32	5.08	3.52	3.38	7.74	2.86
460-465	0.0	0.0	37.63	12.64	4.12	3.38	3.10	7.08	2.42
465-470	0.98	23.53	37.41	15.10	5.20	4.08	4.14	7.06	2.50
470-475	2.04	20.11	37.83	16.06	5.28	3.94	4.36	8.62	0.0
475-480	0.67	23.68	37.91	13.86	4.64	3.72	3.44	8.54	3.54
480-485	0.66	0.0	36.85	15.52	0.0	3.96	3.98	8.68	3.12
485-490	1.05	24.45	35.09	14.01	5.50	4.18	4.40	8.56	2.76
490-495	2.03	28.06	38.01	12.74	4.18	3.24	2.90	6.88	1.96
495-500	1.88	28.41	37.47	11.68	3.94	3.34	2.78	7.80	2.68
500-505	1.47	27.06	36.37	11.84	4.28	3.42	3.34	8.76	3.46
505-510	1.52	27.13	35.91	12.60	4.58	4.18	3.60	7.64	2.84
510-515	0.99	25.82	34.43	12.36	4.48	4.50	3.90	8.52	5.00
515-520	0.64	26.41	34.31	12.84	5.02	3.90	3.48	7.92	5.48
520-525	0.44	23.79	37.53	13.34	4.92	3.34	2.94	7.70	6.00
525-530	0.41	22.58	36.31	13.68	4.98	3.96	3.08	8.08	6.92
530-535	0.51	24.74	36.31	13.82	4.84	3.56	3.00	7.50	5.72
535-540	0.69	25.24	34.75	14.68	5.34	3.78	2.84	7.50	5.18
540-545	0.66	28.03	35.21	13.38	4.76	3.44	2.72	6.38	5.42
545-550	0.72	28.75	34.01	13.34	4.62	3.36	2.54	7.18	5.48
550-555	0.55	27.28	37.41	12.84	4.22	3.06	2.54	6.22	4.88
555-560	0.56	26.50	37.77	13.32	4.40	3.38	2.54	6.62	4.92
560-565	0.53	27.76	37.85	12.84	4.28	3.30	2.46	6.28	4.70
565-570	0.50	26.83	37.11	13.40	4.54	3.18	2.66	6.56	5.22
570-575	0.54	26.85	36.97	12.32	4.36	3.40	2.62	6.64	5.30
575-580	0.75	25.52	35.27	13.04	7.32	3.58	2.52	6.80	5.20
580-585	0.44	22.73	37.25	15.72	5.26	3.58	2.52	6.80	5.70
585-590	0.39	19.68	36.69	17.40	6.18	3.86	2.88	7.12	5.80
590-595	0.46	23.09	36.35	14.10	5.28	3.80	2.90	7.02	7.00

SITE 2 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
595-600	0.54	22.09	35.01	14.18	5.32	4.06	3.20	9.56	6.04
600-606	0.59	22.42	32.41	14.18	5.98	4.44	4.04	8.78	7.16

SITE 3

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 8	0.55	21.87	24.50	14.60	3.14	7.92	5.44	13.72	8.26
8- 12	0.37	20.59	24.30	14.22	6.38	4.46	4.36	12.76	12.56
12- 16	0.39	19.27	25.66	14.70	6.48	4.42	4.18	11.62	13.28
16- 20	0.38	19.48	24.80	14.44	6.70	4.32	4.26	11.98	13.64
20- 24	0.41	18.75	25.80	14.96	7.04	4.46	4.36	11.54	12.58
24- 28	0.37	20.69	26.58	16.20	7.10	4.42	4.20	9.86	10.58
28- 32	0.37	19.99	30.64	16.08	6.64	4.08	3.86	9.94	8.40
32- 36	0.41	21.97	30.62	14.40	5.96	3.74	3.56	10.52	8.82
36- 41	0.44	21.34	28.02	13.18	5.38	3.74	3.50	13.18	11.22
41- 46	0.55	19.43	27.84	13.16	5.86	4.14	3.76	13.72	11.54
46- 51	0.48	19.70	28.52	13.40	5.80	4.30	4.32	13.36	10.12
51- 56	0.50	23.30	29.36	12.04	5.14	3.96	4.08	12.26	9.36
56- 61	0.46	23.63	32.17	11.94	4.58	3.50	3.58	11.10	9.04
61- 66	0.54	23.92	30.94	11.28	4.60	3.52	3.56	11.32	10.32
66- 71	0.44	23.66	30.82	11.34	4.22	3.60	3.58	11.68	10.66
71- 76	0.71	25.45	27.64	11.06	4.50	3.76	3.96	12.44	10.48
76- 81	0.55	25.49	31.74	11.76	4.34	3.32	3.56	10.64	8.60
81- 86	0.73	26.23	30.34	11.02	4.06	3.46	3.86	11.48	8.22
86- 91	0.88	26.12	29.36	12.28	4.48	3.62	3.20	11.56	8.50
91- 96	0.68	25.10	29.18	12.72	4.64	3.90	3.42	11.06	9.30
96-101	3.45	0.0	30.54	11.16	4.38	3.90	3.92	12.26	0.0
101-103	2.48	26.76	29.38	12.44	4.92	4.38	4.78	13.80	0.0
103-108	1.06	25.94	30.94	13.08	4.82	4.16	4.40	12.96	0.0
108-113	0.97	0.0	36.53	12.54	4.66	4.02	3.78	0.0	0.0
113-118	1.91	0.0	28.88	11.54	4.38	4.94	3.62	0.0	0.0
118-123	1.65	0.0	31.52	12.12	4.86	3.88	3.48	0.0	0.0
129-134	2.48	0.0	30.76	12.36	4.86	3.90	3.34	0.0	0.0
139-144	1.52	0.0	31.44	12.12	4.48	3.54	3.36	0.0	0.0

SITE 3 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
149-154	1.12	0.0	32.85	14.14	5.28	4.04	3.94	0.0	0.0
159-164	1.12	0.0	31.28	14.12	6.02	4.16	4.02	0.0	0.0
169-174	1.01	0.0	30.58	13.46	5.64	4.70	4.36	0.0	0.0
179-184	1.22	0.0	31.14	12.60	5.76	4.62	4.28	0.0	0.0
189-194	1.06	0.0	31.40	12.62	5.42	4.40	4.58	0.0	0.0
199-204	0.62	0.0	35.07	13.60	5.22	4.34	4.42	0.0	0.0
209-214	0.81	0.0	35.15	12.24	4.74	3.68	3.80	0.0	0.0
219-224	0.98	0.0	33.87	12.18	4.88	4.04	3.94	0.0	0.0
229-234	1.04	0.0	35.95	11.58	4.16	3.52	2.64	0.0	0.0
239-244	0.85	0.0	34.67	14.62	4.88	3.58	3.84	0.0	0.0
249-254	1.06	24.43	33.81	15.14	4.52	3.74	3.02	9.12	5.16
259-264	0.81	27.18	34.39	14.34	4.26	3.20	3.30	8.28	4.24
269-274	0.85	21.64	35.57	15.52	5.22	3.44	3.16	9.20	5.40
279-284	0.68	26.41	33.69	13.88	4.58	3.56	3.06	8.74	5.40
289-294	1.68	26.25	33.85	12.76	4.56	3.36	3.00	9.30	5.24
299-304	0.81	28.64	33.53	13.10	4.12	3.40	2.92	8.92	4.56
309-314	0.83	24.38	36.51	13.72	4.96	3.40	2.92	8.70	4.58
319-324	0.68	25.93	34.09	14.16	4.92	3.66	2.72	9.18	4.66
329-334	0.62	26.04	33.01	14.28	4.80	3.70	3.30	9.26	4.98
339-344	0.77	26.80	33.77	13.14	4.60	3.36	3.00	9.60	4.86
349-354	0.56	27.07	33.79	13.80	4.48	3.38	3.06	8.88	4.98
364-369	0.59	26.04	32.59	13.20	5.00	3.98	3.52	10.06	5.02
374-379	0.50	21.19	34.83	14.58	5.20	4.08	3.50	10.38	5.74
384-389	0.79	27.24	34.39	12.66	4.46	3.34	3.10	9.32	4.70
394-399	0.66	26.51	36.01	12.62	3.92	3.34	2.98	9.24	4.72
404-409	0.59	23.92	35.21	14.32	4.70	3.46	3.14	9.20	5.46
414-419	0.29	22.90	37.47	13.80	3.98	3.12	3.22	9.52	5.70
424-429	0.66	24.07	37.37	13.84	4.16	3.00	2.84	8.86	5.20

SITE 3 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
429-434	1.02	24.53	35.81	13.04	4.26	3.24	3.08	9.38	5.64
434-439	0.84	27.47	32.17	13.42	4.52	3.18	3.20	9.36	5.84
439-444	0.32	20.67	32.53	18.58	4.46	3.56	3.28	11.32	5.28
444-449	0.29	24.04	31.73	17.96	4.86	3.16	2.96	9.94	5.06
449-454	0.34	23.69	34.53	16.96	4.50	2.94	2.38	9.56	5.10
454-459	0.27	22.58	36.53	16.82	4.16	2.74	2.14	9.66	5.10
459-464	0.18	23.81	35.23	16.46	4.42	2.46	2.82	9.54	5.08
464-469	0.49	25.26	32.63	16.00	4.70	3.22	2.48	9.96	5.26
469-474	0.20	25.15	33.95	16.82	4.54	2.64	2.26	9.12	5.32
474-479	0.45	23.44	32.55	18.70	5.02	2.96	2.30	8.88	5.70
479-484	0.27	20.68	35.21	18.16	4.56	3.06	2.22	9.90	5.94
484-489	0.36	19.57	33.77	18.24	5.14	3.36	2.52	10.92	6.12
489-494	0.19	17.86	33.53	19.88	5.04	3.52	2.42	10.94	6.62
494-499	0.16	18.19	31.43	19.82	5.88	3.28	2.16	10.16	8.92
499-504	0.56	17.97	31.41	18.66	5.72	3.56	2.24	10.18	9.70
504-509	0.18	20.43	33.47	18.96	4.84	2.62	1.88	8.42	9.20
509-516	0.47	19.68	32.15	18.90	4.90	2.96	2.14	8.78	10.02
516-522	0.55	18.20	26.93	18.14	6.10	3.58	2.84	10.74	12.92
522-525	0.50	18.39	27.49	17.76	5.78	3.42	2.80	12.72	11.14
525-528	0.56	19.21	27.11	17.70	5.78	3.50	2.70	12.96	10.48
528-532	0.92	17.15	27.69	17.44	6.54	3.76	2.44	11.90	12.16
532-536	0.53	19.96	27.11	16.54	6.02	3.60	2.74	12.74	10.76
536-540	0.45	19.50	27.77	14.08	5.08	4.34	3.16	14.58	11.04

SITE 4

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 5	0.94	21.16	25.27	13.15	6.08	3.92	3.30	11.04	15.14
5- 12	0.81	22.29	24.91	13.23	6.18	4.25	3.20	12.18	12.95
12- 17	0.77	21.93	26.14	13.83	5.94	4.61	3.54	11.88	11.36
17- 22	0.71	21.88	27.27	14.12	6.95	6.65	2.78	0.0	0.0
22- 26	0.88	22.14	25.96	13.33	5.90	4.43	3.75	12.26	11.26
26- 31	1.07	20.24	26.26	13.01	6.38	4.31	3.02	10.47	15.24
31- 36	1.03	19.36	25.51	13.87	6.73	4.41	2.92	10.59	15.53
36- 41	1.39	20.90	26.86	12.63	6.14	3.71	3.58	11.30	13.49
41- 46	1.44	20.30	25.96	12.26	6.64	4.31	3.52	12.16	13.47
46- 51	1.07	20.34	28.35	12.00	6.02	4.49	4.39	12.24	11.10
51- 55	1.26	21.11	25.33	13.31	7.87	3.89	3.89	12.59	10.75
55- 59	1.38	27.21	28.01	12.63	4.45	3.87	3.20	10.59	8.66
59- 64	1.14	28.51	28.53	13.61	5.94	4.41	3.30	10.41	10.09
64- 69	0.91	23.47	28.37	13.01	5.52	4.45	3.30	10.90	10.07
69- 74	0.92	24.79	29.66	12.08	5.58	3.87	3.77	10.15	9.18
74- 79	0.85	24.49	27.62	15.12	5.14	4.44	3.74	10.62	7.98
79- 84	1.05	22.95	28.88	14.66	6.00	4.84	3.68	10.32	7.62
84- 89	1.21	25.33	27.46	13.38	5.78	4.80	3.90	11.40	6.74
89- 94	0.96	24.98	29.06	11.30	5.68	4.90	4.00	10.64	8.48
94- 99	1.14	21.96	30.00	15.96	4.06	6.54	3.70	9.22	7.42
99-104	1.12	28.50	29.70	11.26	4.80	4.12	3.44	9.44	7.62
104-109	1.47	27.93	29.66	11.12	5.22	4.32	3.40	9.50	7.38
109-114	1.24	24.62	29.56	14.78	5.48	6.04	1.44	9.46	7.38
114-119	0.84	25.24	30.94	12.34	5.14	4.08	3.54	10.38	6.80
119-124	1.55	22.03	28.80	13.58	5.80	4.68	5.16	10.18	8.22
124-129	1.39	24.45	31.38	13.34	5.52	4.76	2.96	9.72	6.48
129-134	1.13	25.75	30.78	12.88	6.28	4.98	4.64	8.86	4.70
134-139	1.26	27.94	31.00	12.90	4.18	6.92	4.74	6.86	4.20

SITE 4 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
139-145	1.34	23.48	31.38	14.32	6.28	5.10	4.84	8.80	4.46
145-150	0.83	23.25	30.74	14.80	6.54	4.82	4.26	9.42	5.34
150-155	1.06	23.71	32.15	14.00	5.98	4.44	4.20	9.34	5.12
155-160	0.93	22.93	31.90	14.04	5.94	0.0	0.0	9.92	5.48
160-165	0.84	0.0	31.56	13.26	5.98	4.62	3.78	0.0	5.68
165-170	1.79	27.05	31.26	11.74	5.28	4.24	3.92	9.16	5.56
170-175	1.75	25.14	31.44	9.52	5.12	4.38	3.85	12.32	6.48
175-180	0.89	26.48	33.73	12.96	3.32	4.48	4.36	8.34	5.44
180-185	0.77	27.74	33.41	12.72	4.80	2.74	2.74	9.44	5.64
185-190	0.50	23.67	33.69	14.60	4.98	3.66	4.70	8.10	6.10
190-195	0.52	21.93	32.17	16.16	6.70	3.20	4.36	8.78	6.18
195-200	0.81	24.04	32.75	14.20	6.00	3.18	4.46	8.44	6.12
200-205	0.63	23.88	32.61	14.26	5.68	3.14	4.40	8.54	6.86
205-210	0.61	26.61	31.58	12.80	5.10	2.80	3.62	8.90	7.98
215-222	1.25	25.33	31.72	13.04	5.48	2.92	4.02	9.30	6.94
222-227	0.71	24.69	32.04	13.48	5.88	2.78	4.58	9.32	6.52
227-232	0.67	25.59	31.04	13.60	5.66	2.88	3.48	9.08	8.00
232-237	0.73	26.44	32.43	13.10	5.30	3.62	3.44	9.32	5.62
237-242	0.72	23.47	32.27	14.20	4.92	4.02	4.12	9.98	6.30
242-247	0.73	23.32	32.85	13.98	5.90	4.30	3.74	9.22	5.96
247-252	0.66	23.99	33.83	13.82	5.64	3.84	3.64	8.74	5.86
252-257	0.81	22.92	33.37	14.00	5.72	4.12	3.80	8.94	6.32
257-268	0.72	21.05	33.15	14.56	6.60	4.48	4.44	9.46	5.54
268-273	0.83	20.98	34.27	14.08	7.16	3.38	4.44	9.50	5.36
273-278	1.16	20.57	33.27	12.78	9.32	3.72	4.04	8.94	6.20
278-283	1.27	25.46	34.49	12.52	4.96	3.14	3.48	8.22	6.46
283-288	1.01	19.76	34.29	16.52	5.14	3.84	3.92	8.36	7.16
288-296	1.60	25.23	34.79	13.74	4.10	4.50	3.92	7.46	4.66

SITE 4 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
296-302	1.10	23.87	34.87	13.50	4.62	4.36	3.68	8.78	5.22
302-308	0.77	24.00	33.83	13.64	5.02	4.66	5.16	7.82	5.10
308-315	0.85	25.04	34.37	14.40	4.86	2.56	4.06	8.72	5.14
315-320	0.61	20.80	32.83	15.32	5.38	4.40	3.54	9.90	7.22
320-325	0.34	19.29	36.01	15.32	4.88	4.00	2.72	9.74	7.70
325-330	0.33	18.60	33.33	16.16	6.00	3.00	2.82	10.14	9.62
330-335	0.32	15.30	29.70	18.30	7.82	5.06	2.94	10.12	10.44
335-340	0.36	18.46	31.84	15.98	6.24	4.52	3.06	10.88	8.66
340-345	0.30	16.24	31.94	17.54	6.72	5.90	2.18	10.22	8.96
345-350	0.38	14.88	30.80	19.00	7.46	4.90	3.24	10.42	8.92
350-353	0.30	16.32	30.34	18.14	7.60	4.56	2.74	8.22	11.78
353-356	0.29	17.17	30.16	17.62	7.58	4.52	2.80	8.22	11.64
356-362	0.71	18.03	27.72	16.80	8.12	4.92	3.62	9.34	10.74
362-367	0.83	17.53	28.38	16.74	7.62	5.44	4.06	10.06	9.34
367-374	1.02	17.78	26.66	15.96	7.40	5.30	3.92	11.92	10.04

SITE 5

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 6	0.78	21.16	26.30	13.34	6.02	4.36	8.70	11.80	7.54
6- 11	0.69	20.63	26.38	12.86	5.96	4.32	4.44	14.18	10.54
11- 15	0.66	17.94	25.06	12.40	6.54	3.38	3.22	13.54	17.26
15- 20	0.76	0.0	24.70	12.58	6.04	0.0	5.06	14.18	16.26
20- 24	0.87	18.03	24.76	12.54	6.24	3.84	3.40	15.54	14.78
24- 30	1.01	18.81	25.20	12.44	6.10	4.08	4.16	15.48	12.72
30- 35	1.06	20.34	26.14	12.58	6.36	4.14	4.50	14.46	10.42
35- 39	1.03	20.97	28.14	12.62	6.02	4.18	4.66	13.22	9.16
39- 43	0.89	20.95	29.06	12.86	5.76	4.22	4.32	12.96	8.98
43- 48	1.11	21.79	30.06	12.42	5.64	4.42	4.42	12.20	7.94
48- 53	1.13	21.23	28.44	12.34	6.42	4.58	4.46	12.36	9.04
53- 58	1.15	19.83	29.90	12.72	5.88	4.54	4.34	14.16	7.48
58- 63	1.29	24.73	29.34	11.80	5.44	3.98	4.24	11.30	7.88
63- 68	0.85	23.47	31.20	12.14	5.18	4.02	4.10	10.80	8.24
68- 73	1.06	22.80	31.94	12.70	5.60	3.78	4.06	10.56	7.50
73- 78	1.11	22.06	32.09	13.14	5.90	3.82	3.88	10.44	7.56
78- 83	1.10	22.94	31.40	13.08	5.72	4.12	4.06	10.58	7.00
83- 87	1.19	22.63	31.78	14.06	6.68	4.56	4.90	10.14	4.06
87- 92	1.29	21.49	31.18	16.10	6.70	5.18	4.84	9.46	3.76
92- 97	1.24	22.00	31.42	14.14	6.64	5.26	5.42	10.12	3.76
97-102	1.50	22.04	31.04	14.40	6.98	5.48	5.40	9.56	3.60
102-107	2.08	20.51	30.02	15.14	7.08	5.88	5.46	10.10	3.72
107-112	2.07	21.07	31.94	15.38	7.04	5.44	5.04	9.10	2.92
112-117	1.92	20.86	31.60	16.44	7.26	5.16	4.98	9.06	2.72
117-122	1.60	17.46	30.44	16.28	8.96	6.68	6.20	9.28	3.10
122-127	1.18	17.28	30.96	16.84	8.22	5.68	5.22	9.72	4.90
127-132	2.32	19.50	30.04	14.30	7.28	5.34	5.16	11.40	4.66
132-137	1.78	21.22	29.38	13.46	6.96	5.46	5.26	11.66	4.82

SITE 5 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
137-142	0.64	22.99	33.47	13.16	5.56	4.20	4.28	10.68	5.22
142-147	0.94	21.15	33.83	13.82	6.06	4.30	4.38	10.06	5.46
147-152	0.60	20.99	34.55	14.26	5.82	4.14	4.24	9.40	5.64
152-157	0.72	17.91	32.63	16.70	6.78	4.96	4.46	10.72	5.12
157-162	0.81	18.96	32.23	15.36	7.08	4.78	4.52	11.08	5.18
162-167	1.02	18.72	31.62	16.08	7.16	4.76	4.64	10.30	5.70
167-172	0.86	19.69	33.43	14.86	6.54	4.30	4.86	10.90	4.56
172-177	0.84	20.10	34.41	14.58	6.26	4.10	4.12	10.06	5.54
177-182	0.70	21.11	33.79	14.70	6.00	4.10	4.08	9.68	5.84
182-187	0.58	19.01	33.41	16.08	6.72	4.32	4.32	10.66	4.90
187-192	0.74	18.89	32.97	17.64	6.96	4.70	4.20	9.32	5.28
192-197	0.76	20.26	32.97	16.06	6.88	4.86	4.48	9.46	4.28
197-202	0.76	21.27	33.99	16.10	6.42	4.34	4.12	8.96	4.04
202-207	0.65	20.94	32.27	16.38	6.66	4.90	4.60	9.32	4.28
207-212	0.54	0.0	33.09	16.06	6.90	5.02	0.0	0.0	0.0
212-217	0.52	19.67	33.87	15.90	6.32	4.88	4.58	9.22	5.04
217-222	0.51	20.80	34.51	16.00	6.18	4.32	4.62	8.38	5.28
222-227	0.74	20.41	34.65	16.30	5.98	4.40	4.38	8.52	4.62
227-232	0.61	20.79	35.45	15.88	5.76	4.32	3.88	8.84	4.48
232-237	0.76	20.79	35.33	15.22	5.82	4.06	3.60	8.94	5.48
237-242	0.43	15.82	33.09	17.04	6.18	4.22	3.96	9.54	9.72
242-247	0.60	16.53	33.55	17.06	6.46	4.46	4.22	9.86	7.26
247-253	0.29	18.61	31.24	16.60	6.22	4.02	3.58	9.92	9.52
253-258	0.29	16.64	32.15	17.34	6.46	4.10	3.84	10.32	8.86
258-263	0.36	16.41	33.77	17.18	6.04	3.94	3.58	9.62	9.10
263-268	0.49	16.06	34.35	16.82	5.70	3.94	3.26	9.08	10.30
268-273	0.56	15.42	29.94	17.80	7.06	4.78	3.78	10.28	10.38
273-278	2.52	14.58	29.12	17.26	7.84	5.10	4.08	9.68	9.82

SITE 5 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
278-285	0.29	15.73	30.60	17.80	7.58	5.62	4.28	8.66	10.24
285-288	1.33	15.99	23.08	15.54	8.18	6.34	5.46	12.74	11.34

SITE 6

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 6	0.91	9.85	24.58	20.72	6.68	4.44	3.20	14.90	14.72
6- 10	0.83	14.85	23.98	14.36	6.98	4.48	3.90	12.20	18.42
10- 14	0.94	12.02	23.72	14.90	7.34	4.24	4.06	12.84	19.94
14- 19	1.10	12.32	22.54	15.58	8.14	4.76	3.86	15.86	15.84
19- 24	1.11	12.27	23.06	15.06	7.92	4.88	4.32	14.66	16.78
24- 28	1.02	13.78	24.66	15.14	7.42	5.00	4.44	14.72	13.82
28- 32	1.07	15.03	25.58	14.72	7.42	4.94	4.56	13.96	12.72
32- 37	1.11	15.21	27.46	16.08	7.14	5.06	4.42	13.48	10.04
37- 42	1.08	18.18	27.12	14.90	6.88	4.78	4.30	12.70	10.06
42- 48	0.95	16.03	26.98	16.84	7.86	4.30	4.16	11.98	10.90
48- 54	0.97	13.75	27.06	18.12	7.70	5.12	4.54	12.12	10.62
54- 59	0.74	13.82	26.52	18.18	8.60	5.28	4.64	12.00	10.22
59- 64	0.84	14.00	26.90	17.80	8.08	5.36	4.72	12.34	9.96
64- 69	0.94	15.14	27.34	17.40	8.24	5.34	4.46	12.20	8.94
69- 74	0.65	13.01	28.00	17.46	8.04	5.46	4.52	12.76	10.10
74- 79	0.77	14.23	27.38	17.72	8.36	5.46	4.54	12.38	9.16
79- 84	0.82	12.64	28.26	19.70	8.90	5.34	4.60	11.38	8.36
84- 89	1.10	14.70	28.68	18.50	8.14	5.38	4.62	11.00	7.80
89- 94	0.92	14.48	30.64	18.68	8.24	4.90	3.92	10.78	7.44
94- 99	0.70	0.0	29.34	0.0	0.0	4.64	6.12	9.34	9.62
99-104	0.80	13.26	31.84	18.80	8.62	5.64	5.00	10.54	5.50
104-109	1.00	16.27	32.57	17.86	7.36	5.00	4.78	9.66	5.50
109-114	0.85	14.77	31.02	19.02	7.72	5.24	5.04	10.30	6.04
114-119	0.64	14.00	29.72	18.74	8.64	5.64	5.44	8.90	8.28
119-124	0.96	11.50	30.74	19.76	7.68	4.92	4.80	10.04	9.60
124-129	1.22	13.94	31.88	19.14	8.28	5.04	4.74	10.24	5.52
129-136	0.85	17.27	31.26	17.22	7.18	4.54	4.30	10.42	6.96
136-140	0.98	14.47	33.37	17.88	6.48	4.58	4.24	11.00	7.00

SITE 6 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
140-145	0.87	15.62	33.55	15.86	6.68	4.88	4.46	11.28	6.80
145-150	0.62	16.26	31.54	17.20	6.88	4.56	4.52	11.38	7.04
150-155	1.05	15.82	32.81	17.34	6.88	4.52	4.30	10.58	6.70
155-160	0.96	17.85	32.39	16.56	6.80	4.08	4.16	11.14	6.06
160-165	0.79	16.92	33.03	17.26	6.66	4.12	4.42	10.60	6.20
165-170	0.47	16.04	32.79	17.44	6.70	4.64	4.56	9.30	8.06
170-175	0.43	14.44	33.27	18.22	7.34	4.66	5.14	10.36	6.14
175-180	0.44	13.92	32.57	17.62	7.42	4.80	4.38	11.33	7.52
180-185	0.39	10.95	29.26	19.68	8.26	4.62	4.36	11.66	10.82
185-192	1.11	11.51	25.80	19.42	7.94	4.86	3.68	11.30	11.68
192-195	1.15	10.37	23.94	19.10	9.88	5.78	3.90	10.40	15.48
195-197	2.69	12.91	23.64	17.10	8.70	5.18	4.04	10.72	15.02

SITE 7 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
137-142	1.32	19.63	32.11	15.80	6.42	3.92	3.92	8.72	8.16
142-147	0.84	17.93	33.47	16.80	6.54	3.64	3.54	9.12	8.12
147-152	0.96	18.08	30.82	16.90	7.08	3.78	4.22	9.54	8.62
152-157	0.61	11.63	29.32	19.92	8.64	4.94	4.28	8.74	11.92
157-161	0.25	8.59	25.56	21.30	10.46	5.58	4.24	10.56	13.46
161-164	2.12	9.30	22.96	20.18	10.46	5.84	3.94	9.22	15.98

SITE 7

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 6	1.54	18.26	24.14	14.74	7.08	5.00	3.56	12.16	13.52
6- 11	1.33	16.81	24.18	15.10	6.24	5.92	3.66	12.00	14.76
11- 16	1.34	15.00	23.60	15.18	9.54	2.76	4.16	11.30	17.12
15- 19	1.17	14.75	23.30	14.72	7.84	5.34	6.18	13.22	0.0
19- 22	1.43	14.79	22.80	14.20	8.12	4.34	4.28	9.84	20.20
22- 25	1.57	16.41	22.60	14.32	6.36	4.36	3.58	11.10	19.70
25- 29	1.48	12.98	22.80	14.68	7.86	4.14	3.66	11.54	21.58
29- 33	1.31	14.69	21.44	14.08	7.24	4.10	3.86	12.88	20.40
33- 38	0.86	12.90	21.74	13.96	7.36	4.50	4.40	13.02	21.26
38- 46	0.87	14.05	24.58	14.68	7.92	4.48	5.20	13.54	14.68
46- 51	0.85	14.75	24.92	14.90	7.54	4.60	4.76	12.86	14.82
51- 55	1.06	13.52	25.58	15.38	8.12	4.26	4.90	12.70	14.48
55- 60	0.85	13.57	25.96	15.86	8.14	4.36	4.80	12.54	13.92
60- 65	0.58	15.08	26.76	14.80	7.56	4.42	4.60	12.50	13.70
65- 70	0.49	16.19	26.40	14.78	7.68	4.02	4.86	11.48	14.10
70- 75	0.72	14.82	26.74	16.18	8.20	4.16	5.14	11.42	12.62
75- 80	0.76	15.54	28.00	16.10	8.10	4.16	4.64	11.10	11.60
80- 85	1.02	15.76	29.92	15.56	7.72	4.00	4.90	10.42	10.70
85- 90	0.86	14.18	29.62	17.56	8.50	3.62	4.58	10.08	11.00
90- 95	0.73	13.55	29.86	18.36	8.66	4.04	4.44	9.86	10.50
95-100	0.80	15.38	30.56	16.98	8.16	4.36	5.14	10.22	8.40
100-105	1.00	13.99	32.49	16.26	8.26	4.30	5.60	11.06	7.04
105-109	0.92	14.57	31.02	18.16	7.96	4.86	4.96	10.16	7.40
109-114	1.11	13.63	31.04	19.02	8.08	4.64	4.86	10.96	6.30
114-120	1.15	13.87	30.20	19.60	8.46	5.06	4.66	10.66	6.34
120-126	1.10	15.32	31.32	18.18	8.24	4.86	4.54	9.88	6.56
126-132	1.56	17.37	30.28	17.08	7.34	4.32	4.48	10.50	7.08
132-137	1.49	18.24	32.29	16.60	6.48	4.20	4.00	10.32	6.38

SITE 8

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 8	1.62	17.12	24.38	15.79	7.25	5.38	3.24	11.22	14.00
8- 13	1.33	17.36	22.69	15.97	7.09	5.14	3.56	10.43	16.43
13- 18	1.50	16.56	22.49	15.34	6.44	6.18	3.52	9.32	18.65
18- 25	1.78	0.0	21.99	15.22	7.95	0.0	0.0	10.85	19.01
25- 30	1.35	15.06	24.77	10.45	7.49	5.26	3.20	12.38	20.04
30- 34	1.10	13.66	20.98	14.46	8.66	5.06	2.07	14.40	19.61
34- 39	1.04	13.96	20.68	15.10	7.83	5.48	4.27	14.48	17.16
39- 44	1.03	17.65	23.40	13.71	7.15	5.28	5.38	13.07	13.33
44- 49	1.34	17.37	23.80	15.10	6.83	5.38	4.47	13.31	12.40
49- 54	1.11	14.70	22.98	15.81	8.42	5.52	4.19	13.33	13.94
54- 59	1.00	15.34	22.51	15.93	7.77	5.22	4.67	12.46	15.10
59- 64	0.56	8.15	33.89	14.12	7.89	4.39	4.83	12.32	13.85
64- 69	0.38	18.50	24.69	15.28	5.24	6.20	3.75	12.81	13.15
69- 74	0.50	18.49	26.14	15.28	5.18	5.74	4.11	12.12	12.44
74- 79	0.82	18.37	26.44	14.90	5.66	5.98	4.27	11.62	11.94
79- 83	0.86	18.00	27.26	15.52	5.84	5.80	3.77	10.79	12.16
83- 88	0.70	16.90	27.71	15.55	6.18	5.74	4.01	10.81	12.40
88- 93	0.24	16.76	27.59	15.24	6.54	5.80	4.13	11.48	12.22
93- 98	0.46	15.72	27.89	16.29	6.24	5.50	4.14	10.39	13.37
98-103	0.37	16.48	27.93	15.12	6.60	5.52	6.50	7.85	13.63
103-108	0.52	17.08	29.44	15.34	6.26	3.91	5.08	9.91	12.46
108-113	0.48	16.23	28.74	15.93	6.12	5.72	4.01	10.43	12.34
113-118	0.80	16.49	29.78	16.98	6.06	5.72	4.07	9.79	10.31
118-125	0.68	17.83	30.85	17.00	5.30	4.91	3.77	8.64	11.02
125-130	0.80	14.92	30.59	17.90	6.26	5.18	3.79	9.91	10.65
130-133	0.38	13.89	30.14	18.04	6.24	5.32	4.21	9.54	12.24
133-138	0.35	0.0	29.30	18.18	6.64	0.0	0.0	10.47	12.26
138-144	0.44	17.23	25.98	18.44	6.64	5.84	3.42	10.71	11.30

SITE 8 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
144-150	1.19	13.52	20.54	19.61	8.88	7.27	3.64	9.60	15.65
150-156	1.68	13.57	22.84	18.99	8.68	6.97	3.71	9.00	14.56

SITE 9

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 6	1.06	14.12	15.00	25.66	8.28	4.90	5.48	12.66	12.84
6- 9	1.32	14.68	24.56	17.80	7.26	5.04	4.94	11.36	13.04
9- 12	1.44	13.78	23.18	15.92	8.40	4.60	3.96	11.24	17.48
12- 17	1.40	12.20	22.44	15.76	7.86	4.24	4.68	11.36	20.06
17- 22	1.35	11.77	20.70	15.66	7.84	4.06	4.70	13.32	20.60
22- 25	1.24	10.76	19.94	15.12	7.98	4.44	4.76	15.56	20.20
25- 28	1.64	9.46	19.98	15.58	8.00	4.50	5.40	16.32	19.12
28- 32	2.10	11.44	20.96	15.56	8.14	5.04	5.50	16.98	14.28
32- 36	1.70	11.64	21.82	15.84	8.56	5.38	6.22	15.74	13.10
36- 41	1.58	12.08	23.36	15.22	8.02	5.22	6.16	16.16	12.20
41- 46	2.05	10.91	25.14	15.94	7.92	5.36	6.22	14.72	11.74
46- 52	1.13	11.73	23.90	15.60	7.78	4.40	5.46	14.14	15.86
52- 56	1.94	12.28	26.86	16.56	6.86	5.52	5.70	12.92	11.36
56- 58	1.46	12.60	25.02	16.68	8.28	4.96	5.56	11.98	13.46
58- 63	0.35	12.59	27.62	18.08	7.84	4.34	4.98	12.22	11.98
63- 68	0.30	12.64	27.50	17.30	7.70	4.38	5.00	11.92	13.26
68- 73	0.45	11.57	28.52	16.56	7.82	5.32	4.50	13.82	11.44
73- 78	0.45	11.35	26.94	17.90	8.78	5.68	5.02	12.42	11.46
78- 83	0.36	12.42	29.74	18.86	9.26	5.80	5.28	10.82	7.46
83- 88	0.43	14.13	31.00	18.18	7.88	5.12	5.56	10.66	7.04
88- 94	0.74	12.12	30.04	18.66	8.58	5.46	5.48	11.92	7.00
94- 99	0.98	14.76	31.76	18.66	8.10	5.32	5.40	9.80	5.22
99-104	0.62	15.06	31.02	17.82	8.42	4.88	5.28	10.68	6.22
104-109	0.74	13.76	31.04	18.74	7.50	4.70	4.74	10.86	7.92
109-114	0.59	12.79	31.86	18.74	6.88	4.14	3.78	11.20	10.02
114-120	0.33	11.27	29.56	20.16	8.38	4.94	4.32	9.16	11.88
120-126	0.31	8.11	25.40	22.14	10.28	5.88	4.36	11.56	11.96
126-131	0.26	6.80	21.50	22.66	12.40	7.00	4.78	11.20	13.40

SITE 9 (CONTINUED)

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
131-136	0.76	9.32	22.08	19.26	10.70	6.10	4.42	9.30	18.06
136-140	1.60	11.04	21.08	16.82	8.40	5.28	4.04	11.18	20.56

SITE 10

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 8	2.22	14.03	23.94	18.75	13.51	9.26	9.10	9.28	0.0
8- 13	0.92	12.99	24.24	14.70	7.15	5.16	3.18	11.12	21.45
13- 18	0.74	7.62	28.21	11.58	5.44	5.06	2.82	11.26	27.27
18- 22	0.84	12.36	18.24	11.94	6.48	4.73	3.26	14.22	27.93
22- 26	2.42	11.14	19.73	12.24	6.14	6.06	4.37	17.18	20.72
26- 31	1.87	10.78	19.15	13.89	8.84	2.82	3.59	17.92	21.14
31- 36	1.84	10.80	25.15	7.98	7.59	5.84	4.15	15.81	20.84
36- 42	1.82	9.22	23.38	14.76	6.12	5.66	5.01	14.82	19.21
42- 47	1.52	17.30	20.78	17.08	5.88	5.36	5.36	15.28	17.32
47- 52	1.57	11.58	22.27	16.09	6.91	6.04	4.65	16.75	14.14
52- 57	0.67	12.03	23.60	17.66	7.09	5.56	4.05	15.22	14.12
57- 62	0.64	18.28	17.84	17.86	7.05	5.98	3.81	14.32	14.22
62- 66	1.28	10.82	25.21	17.52	7.69	5.84	3.60	14.21	13.83
66- 68	1.64	10.96	25.71	18.08	7.69	5.76	3.89	13.79	12.48
68- 73	0.29	6.64	27.00	24.61	6.73	4.97	2.84	13.21	13.71
73- 78	0.56	11.61	27.87	17.72	7.65	4.67	3.52	13.41	12.99
78- 83	0.88	11.75	27.83	18.30	7.25	4.75	3.99	12.22	13.03
83- 86	0.37	0.0	29.96	18.02	7.05	4.51	0.0	0.0	12.67
86- 96	0.52	12.08	27.47	18.91	5.76	7.15	4.51	10.71	12.81
96-100	0.32	0.0	27.41	19.75	12.95	0.0	0.0	0.0	0.0
100-103	0.11	8.15	24.28	19.61	9.56	8.04	2.76	9.99	17.50
103-108	1.32	9.60	19.84	17.38	8.36	5.80	4.89	10.96	21.85
108-113	2.30	16.69	38.02	11.92	5.01	2.74	2.60	6.14	14.58

SITE 11

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 6	0.14	14.75	28.51	18.02	6.81	4.61	5.94	14.80	0.0
6- 11	0.84	11.76	24.81	16.55	7.75	4.27	3.86	13.56	17.20
11- 17	1.00	5.54	20.84	14.18	10.57	3.89	3.88	15.94	24.16
17- 22	0.76	8.37	19.23	9.52	6.22	3.64	4.16	18.46	29.64
22- 27	0.89	8.81	18.18	12.73	6.87	3.69	4.04	24.68	20.10
27- 32	0.91	8.87	20.66	12.42	8.30	3.83	4.52	19.86	20.64
32- 37	1.34	9.24	21.47	14.44	7.01	4.03	5.22	20.82	16.42
37- 42	1.59	0.0	22.88	16.19	7.19	0.0	5.64	19.86	14.14
42- 48	0.48	11.51	24.55	16.15	7.39	4.11	6.59	14.16	15.06
48- 53	0.77	13.78	26.66	16.85	7.43	3.24	5.80	12.30	13.17
53- 58	1.22	11.96	28.51	17.90	7.57	3.50	5.40	10.77	13.17
58- 64	1.32	10.02	26.20	18.22	7.63	3.75	5.90	10.91	16.05
64- 68	0.99	10.26	25.76	23.52	0.0	3.95	4.71	11.94	15.81
68- 75	0.24	9.99	24.04	19.98	8.54	4.27	4.13	13.49	15.32
75- 80	0.46	11.00	27.14	15.91	7.27	4.09	6.44	12.59	15.10
80- 85	0.72	11.92	26.94	16.07	6.40	3.85	6.10	13.92	14.08
85- 90	0.61	9.28	30.81	14.20	7.95	3.81	6.56	13.33	13.45
90- 96	1.31	10.73	29.48	14.62	7.45	3.60	5.88	9.63	17.30
96-102	0.10	8.76	28.82	17.68	8.60	4.51	5.68	9.42	16.43

SITE 12

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 5	1.64	15.29	28.94	17.68	7.97	5.46	4.03	8.88	10.11
5- 7	1.61	13.92	29.94	17.98	8.24	5.52	3.66	9.42	9.71
7- 14	1.86	14.30	28.07	17.88	9.14	5.48	4.03	8.04	11.20
14- 19	2.40	13.15	26.40	16.85	9.06	5.20	4.27	9.08	13.59
19- 24	2.26	12.52	21.16	14.74	7.59	4.59	4.13	12.97	20.04
24- 29	1.06	12.11	14.88	11.48	6.22	3.38	3.06	15.75	32.06
29- 33	1.33	11.10	16.55	12.00	6.30	3.97	4.45	16.11	28.19
33- 38	1.24	11.91	18.12	12.64	6.77	4.07	4.49	14.56	26.20
38- 43	1.78	10.94	19.31	14.18	7.17	4.27	4.07	14.22	24.06
43- 47	0.49	10.96	21.59	14.76	7.81	3.91	4.45	12.75	23.28
47- 52	0.22	12.06	21.59	16.63	8.08	4.55	5.16	12.44	19.27
52- 55	0.29	12.07	23.22	16.94	8.26	4.93	4.67	11.58	18.04
55- 58	0.51	0.0	22.31	18.67	12.57	0.0	3.30	14.42	16.55
58- 62	0.71	10.99	24.14	17.96	7.83	5.74	4.01	14.32	14.30
62- 64	4.20	13.86	21.99	16.25	7.21	5.66	3.85	13.29	13.69
64- 69	0.95	14.10	20.98	23.92	7.37	4.87	3.02	12.16	12.63
69- 73	0.84	12.96	27.57	18.57	7.69	5.08	3.87	11.08	12.34
73- 78	0.76	15.97	27.63	18.87	7.33	4.99	3.46	11.42	12.57
78- 83	0.82	11.94	25.84	18.30	8.24	5.30	4.19	5.80	19.57
83- 88	1.83	11.57	22.29	17.90	8.89	5.80	3.30	11.38	17.04
88- 92	1.68	12.55	20.64	18.69	8.98	5.96	3.24	11.32	16.94

SITE 13

DEPTH (IN.)	PARTICLE SIZE (MICRONS) > 62 %	31-62 %	16-31 %	8-16 %	4-8 %	2-4 %	1-2 %	0.5-1 %	< 0.5 %
0- 8	1.63	13.31	28.18	21.16	8.20	4.02	4.26	10.10	9.14
8- 12	2.24	11.90	26.68	20.04	9.02	6.46	4.84	8.14	10.68
12- 16	3.68	11.08	24.10	16.84	7.24	7.86	4.60	10.32	14.28
16- 21	1.86	6.62	15.64	12.40	7.74	4.86	3.60	15.26	32.02
21- 26	0.97	8.21	16.12	13.18	6.40	3.18	5.80	14.44	31.70
26- 30	1.11	7.55	17.86	13.54	6.70	5.30	4.04	15.82	28.08
30- 35	1.35	8.45	16.66	16.56	7.46	5.40	4.12	14.98	25.02
35- 40	0.59	9.75	19.12	15.44	7.06	5.68	4.10	13.64	24.62
40- 44	0.71	17.45	13.40	16.32	7.68	5.74	4.28	14.42	19.70
44- 49	0.50	10.36	22.38	17.96	7.78	5.78	4.18	14.36	16.70
49- 54	0.80	10.92	22.16	17.58	8.02	5.62	4.52	14.12	16.26
54- 59	1.70	9.96	23.74	16.60	9.12	6.32	4.70	13.80	14.06
59- 65	1.77	9.63	24.38	18.64	8.60	6.24	5.20	12.44	13.10
65- 68	1.90	10.18	23.88	22.24	5.32	5.88	4.80	11.92	13.88
68- 75	0.88	8.32	21.20	20.18	11.54	7.04	4.10	9.88	16.86
75- 80	3.06	10.28	19.50	18.86	12.10	6.78	3.96	8.30	17.16
80- 85	1.41	12.43	22.72	17.42	12.72	5.94	3.48	7.24	16.64
85- 88	2.13	20.21	16.32	8.86	4.90	2.92	5.86	17.22	26.00

APPENDIX F

RAW DATA

SITE 2

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 5	11.7	0.0	1.79	5.75	0.81	0.32	88.64	6.62	4.73
5- 10	11.7	0.0	1.52	5.84	0.86	0.34	91.52	7.89	0.58
10- 15	11.7	0.0	1.13	5.92	0.94	0.35	86.34	7.84	5.80
15- 20	11.7	0.0	0.70	6.02	1.04	0.38	74.17	11.11	14.71
20- 25	11.7	0.0	0.47	6.19	1.04	0.40	60.08	25.63	14.28
25- 30	11.7	0.0	0.20	6.30	1.06	0.49	52.43	28.65	18.90
30- 36	11.7	0.0	0.15	6.65	1.13	0.62	52.94	26.05	21.00
48- 52	11.7	0.0	0.0	6.82	1.09	0.54	51.60	28.27	20.11
52- 55	11.7	0.0	0.0	6.70	1.02	0.53	75.53	11.02	13.44
55- 60	11.7	0.0	0.0	6.61	1.02	0.57	71.20	10.52	18.26
60- 65	11.7	0.0		6.83	1.02	0.59			
65- 70	11.7	0.0	0.0	6.65	1.12	0.80	46.58	13.35	40.06
70- 75	11.7	0.0		6.80	0.99	0.49			
75- 80	11.7	0.0	0.0	6.85	0.92	0.39	32.80	47.77	19.42
80- 85	11.7	0.0		6.72	0.98	0.56			
85- 90	11.7	0.0	0.0	7.05	0.95	0.41	58.67	29.20	12.12
90- 95	11.7	4.07		6.99	0.84	0.48			
95-100	11.7	5.00	0.58	7.55	0.79	0.44	41.66	35.41	22.91
100-105	11.7	6.78		7.65	0.81	0.37			
105-110	11.7	6.78		7.80	0.81	0.39			
110-115	11.7	7.28	0.0	7.76	0.83	0.42	46.39	28.86	24.74
115-120	11.7	6.78		7.77	0.83	0.32			
120-125	11.7	5.91		7.80	0.81	0.32			
130-135	11.7	5.91		7.02	0.88	0.43			
140-145	11.7	6.82		7.43	0.84	0.44			
150-155	11.7	7.25	0.0	7.69	0.91	0.39	34.07	33.79	32.13
160-165	11.7	6.37		7.75	0.84	0.41			
170-175	11.7	6.37		7.63	1.02	0.70			

SITE 2 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
180-185	11.7	8.64		7.75	0.87	0.44			
190-195	11.7	6.82	5.00	7.82	0.87	0.43	13.87	2.28	23.84
200-205	11.7	7.25		7.80	0.84	0.42			
210-215	11.7	4.09		7.72	0.81	0.47			
220-225	11.7	6.37		7.90	0.76	0.38			
230-235	11.7	7.25	0.0	7.91	0.74	0.41	32.28	39.56	28.15
240-245	11.7	6.37		7.84	0.77	0.46			
250-255	11.7	7.73		7.86	0.71	0.43			
260-265	11.7	6.82		7.93	0.86	0.68			
270-275	11.7	6.82		7.73	0.80	0.55			
280-285	11.7	7.73	0.0	7.79	0.81	0.22	49.13	28.39	22.46
290-295	11.7	7.28		7.88	0.86	0.19			
300-305	11.7	7.73		7.88	0.82	0.15			
310-315	11.7	5.91		7.86	0.86	0.14			
320-325	11.7	7.28	0.0	7.85	0.75	0.09	52.87	35.95	11.17
330-335	11.7	5.91		7.84	0.59	0.05			
340-345	11.7	7.21		7.91	0.76	0.23			
350-355	11.7	6.37		7.91	0.59	0.07			
360-365	11.7	7.25	0.0	7.73	0.59	0.24	50.00	28.44	21.55
370-375	11.7	5.91		7.71	0.38	0.15			
380-385	11.7	7.73		7.80	0.59	0.29			
390-395	11.7	6.37		7.70	0.58	0.23			
400-405	11.7	7.28		7.89	0.66	0.23			
410-415	11.7	8.19		7.76	0.71	0.29			
420-425	11.7	6.82	0.0	7.81	0.76	0.31	48.25	35.82	15.92
430-435	11.7	6.37		7.94	0.51	0.29			
440-445	11.7	8.19		7.97	0.82	0.42			
450-455	11.7	7.73		8.01	0.51	0.43			

SITE 2 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
455-460	11.7	7.73		7.93	0.0	0.0			
460-465	11.7	8.19		7.98	0.44	0.22			
465-470	11.7	8.19	0.0	8.00	0.0	0.0	45.28	23.89	30.81
470-475	11.7	8.64		7.90	1.17	1.60			
475-480	11.7	6.82		7.78	0.0	0.0			
480-485	11.7	3.63		7.94	0.60	0.56			
485-490	11.7	3.63		7.51	0.0	0.0			
490-495	11.7	4.09	0.0	7.51	0.99	1.06	24.47	5.67	60.85
495-500	11.7	5.46		7.80	0.0	0.0			
500-505	11.7	4.55		7.36	0.47	0.61			
505-510	11.7	4.55		7.60	0.0	0.0			
510-515	11.7	2.27		7.59	0.75	0.82			
515-520	11.7	1.82	0.36	7.55	0.0	0.0	64.26	30.13	5.60
520-525	11.7	0.0		7.13	0.38	0.05			
525-530	11.7	0.0		7.57	0.0	0.0			
530-535	11.7	0.0		7.49	0.48	0.16			
535-540	11.7	0.0		7.41	0.0	0.0			
540-545	11.7	0.0	0.11	7.33	0.45	0.15	66.57	33.14	3.14
545-550	11.7	0.0		7.25	0.0	0.0			
550-555	11.7	0.91		7.41	0.48	0.17			
555-560	11.7	0.45		7.40	0.0	0.0			
560-565	11.7	0.91		7.49	0.45	0.20			
565-570	11.7	2.73	0.27	7.51	0.0	0.0	68.61	27.00	4.37
570-575	11.7	1.82		7.41	0.43	0.18			
575-580	11.7	5.46	0.62	7.72	0.0	0.0	51.27	25.45	5.09
580-585	11.7	4.09		7.49	0.50	0.18			
585-590	11.7	2.27	0.18	7.41	0.52	0.23	55.38	35.62	8.98
590-595	11.7	0.91	0.09	7.42	0.50	0.14	63.67	33.79	2.50

SITE 2 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
595-600	11.7	1.82	0.31	7.69	0.61	0.15	81.58	13.31	5.09
600-606	11.7	0.0	0.16	7.49	0.70	0.06	87.58	9.65	2.75

SITE 3

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 8	20.7	0.0	2.90	5.43	0.80	0.39	84.25	4.41	11.32
8- 12	20.7	0.0	2.09	5.27	0.77	0.38	79.87	7.54	12.57
12- 16	20.7	0.0	1.73	5.26	0.75	0.35	76.99	5.89	17.10
16- 20	20.7	0.0	1.72	5.49	0.81	0.37	76.84	3.85	19.29
20- 24	20.7	0.0	1.60	5.34	0.76	0.36	59.93	12.19	27.87
24- 28	20.7	0.0	0.98	5.33	0.59	0.27	62.05	13.23	24.70
28- 32	20.7	0.0	0.77	5.58	0.38	0.0	79.93	10.63	9.42
32- 36	20.7	0.0	0.38	5.61	0.32	0.07	83.91	9.35	6.72
36- 41	20.7	0.0	0.26	5.68	0.45	0.05	71.27	20.00	8.72
41- 46	20.7	0.0	0.18	5.69	0.80	0.08	55.73	16.00	28.26
46- 51	20.7	0.0	0.12	5.68	0.58	0.12	65.66	16.07	18.25
51- 56	20.7	0.0	0.09	5.70	0.43	0.08	70.05	25.88	4.06
56- 61	20.7	0.0	0.03	5.70	0.25	0.07	72.53	25.35	2.11
61- 66	20.7	0.0		5.70	0.23	0.06			
66- 71	20.7	0.0	0.0	5.50	0.36	0.06	63.88	32.43	3.68
71- 76	20.7	0.0		5.60	0.42	0.09			
76- 81	20.7	0.0	0.0	5.75	0.34	0.03	60.36	38.86	0.77
81- 86	20.7	0.0		5.80	0.35	0.03			
86- 91	20.7	0.0	0.01	6.10	0.0	0.0	75.51	25.66	0.58
91- 96	20.7	0.0		6.15	0.18	0.03			
96-101	20.7	8.64		7.28	0.0	0.0			
101-103	20.7	6.37	0.70	7.42	3.00	0.24	27.05	19.62	53.31
103-108	20.7	6.82		7.45	0.0	0.0			
108-113	20.7	8.19		7.39	0.54	0.13			
113-118	20.7	8.88	0.0	7.53	0.0	0.0	43.14	31.19	25.65
118-123	20.7	7.73		7.49	0.58	0.68			
129-134	20.7	8.64		7.51	1.21	0.84			
139-144	20.7	7.73		7.50	0.68	0.34			

SITE 3 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
149-154	20.7	6.37	0.0	7.52	0.90	0.35	53.16	21.83	24.92
159-164	20.7	10.00		7.50	0.70	0.14			
169-174	20.7	8.88		7.49	0.82	0.36			
179-184	20.7	2.27		7.60	0.96	0.52			
189-194	20.7	5.00	0.0	7.47	1.02	0.70	47.51	28.72	23.75
199-204	20.7	5.91		7.49	1.14	0.47			
209-214	20.7	6.37		7.48	0.88	0.55			
219-224	20.7	5.91	0.0	7.40	0.95	0.66	50.40	27.91	21.68
229-234	20.7	7.73		7.48	0.92	0.68			
239-244	20.7	10.46		7.56	1.11	0.42			
249-254	20.7	10.00	0.0	7.32	0.80	0.37	52.65	29.79	17.55
259-264	20.7	8.64		7.40	0.85	0.38			
269-274	20.7	8.19	0.0	7.45	0.98	0.42	43.79	27.00	29.19
279-284	20.7	8.88		7.48	0.55	0.28			
289-294	20.7	5.00		7.44	0.81	0.77			
299-304	20.7	5.91	4.44	7.50	0.57	0.18	1.42	85.42	0.08
309-314	20.7	8.88		7.48	0.68	0.30			
319-324	20.7	7.73		7.52	0.67	0.26			
329-334	20.7	7.73	0.0	7.55	0.71	0.47	47.81	33.57	18.61
339-344	20.7	6.82		7.58	0.62	0.31			
349-354	20.7	6.37		7.55	0.79	0.52			
364-369	20.7	4.55	0.0	7.51	0.68	0.28	46.46	37.50	16.03
374-379	20.7	8.64		7.57	0.78	0.69			
384-389	20.7	9.55		7.60	0.73	0.76			
394-399	20.7	10.00	0.0	7.60	0.56	0.41	52.33	37.66	10.00
404-409	20.7	9.10		7.58	0.59	0.43			
414-419	20.7	7.73		7.60	0.93	0.49			
424-429	20.7	8.64		7.63	0.62	0.35			

SITE 3 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
429-434	20.7	8.19		7.62	0.0	0.0			
434-439	20.7	6.37		7.58	0.57	0.38			
439-444	20.7	3.04	0.0	7.05	0.0	0.0	63.67	23.18	13.04
444-449	20.7	5.00		7.21	0.42	0.13			
449-454	20.7	1.36		7.02	0.0	0.0			
454-459	20.7	1.36		7.08	0.34	0.12			
459-464	20.7	2.27	0.0	7.19	0.0	0.0	61.26	30.79	7.93
464-469	20.7	2.27		7.25	0.50	0.10			
469-474	20.7	4.09		7.20	0.0	0.0			
474-479	20.7	2.27		7.22	0.55	0.12			
479-484	20.7	1.36	0.0	7.42	0.0	0.0	52.75	43.10	4.13
484-489	20.7	2.73		7.50	0.57	0.13			
489-494	20.7	0.45		7.42	0.60	0.21			
494-499	20.7	0.91		7.19	0.62	0.72			
499-504	20.7	1.36	0.18	7.10	0.79	0.06	60.00	18.23	21.76
504-509	20.7	1.36	0.19	7.06	0.61	0.06	69.69	27.87	2.42
509-516	20.7	0.91	0.28	7.23	0.64	0.07	50.40	34.40	15.20
516-522	20.7	0.45	0.38	7.31	0.37	0.06	82.94	11.62	5.42
522-525	20.7	0.0		7.28	0.44	0.07			
525-528	20.7	0.0	0.20	7.38	0.44	0.07	84.33	9.15	1.68
528-532	20.7	0.0		7.20	0.55	0.05			
532-536	20.7	0.0	0.15	7.41	0.42	0.07	89.58	8.85	1.56
536-540	20.7	0.0		7.27	0.47	0.07			
540-544	20.7		0.10				95.40	3.44	1.14

SITE 4

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 5	34.7	0.0	2.06	5.31	0.83	0.41	82.10	2.15	15.75
5- 12	34.7	0.0	2.22	5.00	0.82	0.41	86.46	0.45	13.09
12- 17	34.7	0.0	2.27	5.28	0.77	0.38	78.65	2.55	18.79
17- 22	34.7	0.0	2.93	5.49	0.75	0.43	80.46	5.98	13.56
22- 26	34.7	0.0	1.98	5.45	0.85	0.43	74.33	3.63	22.04
26- 31	34.7	0.0	1.20	5.38	0.85	0.40	74.60	4.16	21.24
31- 36	34.7	0.0	0.70	5.56	0.97	0.43	43.51	7.14	49.35
36- 41	34.7	0.0	0.19	5.70	1.04	0.54	39.13	8.04	52.83
41- 46	34.7	0.0	0.46	5.68	1.01	0.46	37.07	10.28	52.65
46- 51	34.7	0.0	0.49	5.78	1.04	0.53	25.43	15.65	58.92
51- 55	34.7	0.0	0.05	5.96	1.10	0.55	29.54	13.35	57.11
55- 59	34.7	0.0	0.0	5.99	0.92	0.45	41.39	22.66	35.95
59- 64	34.7	0.0	0.14	5.85	1.03	0.41	41.93	14.35	43.72
64- 69	34.7	0.0	0.01	6.10	0.94	0.28	49.74	16.33	33.93
69- 74	34.7	0.0	0.0	6.11	0.99	0.29	42.66	37.76	19.58
74- 79	34.7	0.0		6.24	0.90	0.32			
79- 84	34.7	0.0	0.0	6.18	1.04	0.56	28.40	21.96	49.62
84- 89	34.7	0.0	0.0	6.20	0.97	0.65	43.70	20.13	36.15
89- 94	34.7	0.0	0.0	6.04	1.01	0.49	38.68	28.73	32.57
94- 99	34.7	0.0		6.25	1.06	0.55			
99-104	34.7	0.0		6.25	0.91	0.35			
104-109	34.7	0.0	0.0	6.34	1.00	0.59	42.85	29.79	27.34
109-114	34.7	0.0		6.10	1.04	0.44			
114-119	34.7	0.0		6.09	0.95	0.27			
119-124	34.7	0.0	0.0	6.25	0.0	0.0	39.15	28.31	32.53
124-129	34.7	0.0		6.40	1.06	0.62			
129-134	34.7	2.73		6.90	0.0	0.0			
134-139	34.7	6.37	0.71	7.31	0.84	0.42	31.25	27.77	40.97

SITE 4 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
139-145	34.7	2.73		7.14	0.0	0.0			
145-150	34.7	5.00		7.27	0.62	0.29			
150-155	34.7	5.46	0.0	7.26	0.0	0.0	21.73	26.44	51.81
155-160	34.7	5.91		7.23	0.65	0.42			
160-165	34.7	6.82		7.28	0.0	0.0			
165-170	34.7	6.82	7.00	7.40	0.75	0.80	20.33	14.91	64.74
170-175	34.7	5.46		7.49	0.0	0.0			
175-180	34.7	5.91		7.24	0.57	0.55			
180-185	34.7	6.37	0.0	7.28	0.0	0.0	41.78	24.39	26.32
185-190	34.7	5.91		7.20	0.46	0.21			
190-195	34.7	6.37		7.27	0.0	0.0			
195-200	34.7	6.37	0.0	7.54	0.69	0.31	33.65	36.07	30.26
200-205	34.7	6.82		7.49	0.0	0.0			
205-210	34.7	6.37		7.38	0.51	0.30			
215-222	34.7	5.91		7.41	0.79	0.48			
222-227	34.7	6.82		7.41	0.57	0.29			
227-232	34.7	8.19	0.0	7.53	0.72	0.36	44.90	22.86	32.23
232-237	34.7	6.82		7.38	0.0	0.0			
237-242	34.7	6.82		7.58	0.92	0.51			
242-247	34.7	6.82	0.0	7.52	0.0	0.0	37.50	26.78	35.71
247-252	34.7	5.91		7.61	0.73	0.37			
252-257	34.7	5.91		7.60	0.0	0.0			
257-268	34.7	5.91	0.60	7.58	0.69	0.42	46.47	16.97	36.55
268-273	34.7	5.00		7.61	0.0	0.0			
273-278	34.7	6.82		7.69	0.95	0.61			
278-283	34.7	6.37	0.0	7.60	0.0	0.0	80.89	2.80	16.29
283-288	34.7	6.82		7.62	0.85	0.59			
288-296	34.7	5.00		7.50	1.19	1.28			

SITE 4 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
296-302	34.7	4.99	0.0	7.57	0.94	1.22	31.31	11.36	57.32
302-308	34.7	3.88		7.56	0.52	0.78			
308-315	34.7	3.88		7.45	0.58	0.68			
315-320	34.7	1.11	0.0	7.30	0.0	0.0	57.27	10.00	32.72
320-325	34.7	1.11		7.30	0.33	0.09			
325-330	34.7	0.0		7.32	0.0	0.0			
330-335	34.7	0.0	0.0	7.18	0.46	0.11	58.86	19.69	21.44
335-340	34.7	0.0		7.30	0.44	0.16			
340-345	34.7	0.0		7.35	0.52	0.17			
345-350	34.7	0.0	0.0	7.38	0.63	0.27	54.08	18.02	27.88
350-353	34.7	0.0	0.0	7.30	0.20	0.02	73.25	25.22	1.51
353-356	34.7	0.0	0.0	7.20	0.21	0.03	89.16	8.74	2.09
356-362	34.7	0.0	0.0	7.20	0.29	0.05	91.57	5.74	2.68
362-367	34.7	0.0	0.0	7.23	0.44	0.06	94.24	4.54	1.21
367-374	34.7	0.0	0.0	7.11	0.41	0.06	95.87	3.49	0.63
374-379	34.7		0.0				94.17	3.76	2.05
379-382	34.7		0.0				91.55	3.89	4.54

SITE 5

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 6	47.8	0.0	1.35	6.70	0.73	0.42	80.14	4.33	15.52
6- 11	47.8	0.0	2.26	6.38	0.76	0.44	78.14	5.55	16.29
11- 15	47.8	0.0	1.55	6.25	0.81	0.39	71.89	6.50	21.59
15- 20	47.8	0.0	1.54	6.30	0.88	0.42	61.02	9.74	29.23
20- 24	47.8	0.0	1.27	6.28	1.27	0.43	59.40	8.17	32.52
24- 30	47.8	0.0	0.75	6.39	0.89	0.44	42.57	8.57	48.85
30- 35	47.8	0.0	0.65	6.63	0.87	0.44	42.72	11.81	42.42
35- 39	47.8	0.0		6.62	0.84	0.40			
39- 43	47.8	0.0	0.45	6.40	0.87	0.36	31.77	40.64	27.58
43- 48	47.8	0.0	0.23	6.38	0.85	0.46	33.76	31.81	34.41
48- 53	47.8	0.0	0.23	6.40	0.89	0.53	27.27	33.90	38.82
53- 58	47.8	0.0	0.66	6.36	0.91	0.50	29.01	43.51	27.46
58- 63	47.8	0.0		6.58	0.85	0.63			
63- 68	47.8	0.0	0.0	6.60	0.81	0.35	27.52	47.13	25.34
68- 73	47.8	0.0		6.47	0.90	0.54			
73- 78	47.8	0.0	0.12	6.60	0.90	0.51	40.39	28.07	31.52
78- 83	47.8	0.0		6.54	0.92	0.62			
83- 87	47.8	0.0	0.0	6.90	0.88	0.48	20.45	29.45	50.00
87- 92	47.8	4.09		7.55	0.83	0.36			
92- 97	47.8	5.46		7.60	0.76	0.33			
97-102	47.8	5.00	0.0	7.72	0.75	0.39	27.34	22.65	50.00
102-107	47.8	3.64		7.75	0.0	0.0			
107-112	47.8	5.00		7.96	0.74	0.92			
112-117	47.8	4.55		7.95	0.0	0.0			
117-122	47.8	3.64	0.0	7.90	1.56	0.31	23.56	11.78	64.65
122-127	47.8	8.87		7.92	0.0	0.0			
127-132	47.8	10.00		7.80	0.41	0.79			
132-137	47.8	8.19		7.94	0.0	0.0			

SITE 5 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
137-142	47.8	8.46	0.0	8.10	0.56	0.17	44.64	38.92	16.42
142-147	47.8	6.37		7.88	0.0	0.0			
147-152	47.8	5.00		7.66	0.54	0.16			
152-157	47.8	5.46		7.90	0.0	0.0			
157-162	47.8	8.87	0.0	7.95	0.48	0.33	38.29	25.26	36.43
162-167	47.8	6.82		7.90	0.0	0.0			
167-172	47.8	5.91		7.91	0.44	0.44			
172-177	47.8	4.09		7.97	0.56	0.29			
177-182	47.8	4.09	0.0	7.99	0.50	0.30	34.69	27.37	34.93
182-187	47.8	5.91		7.90	0.54	0.32			
187-192	47.8	5.91		7.50	0.0	0.0			
192-197	47.8	5.00		7.70	0.77	0.66			
197-202	47.8	6.82	0.0	7.70	0.0	0.0	25.26	22.53	52.10
202-207	47.8	4.55		7.70	0.59	0.33			
207-212	47.8	3.64		7.70	0.0	0.0			
212-217	47.8	3.64		7.77	0.59	0.32			
217-222	47.8	4.55	0.0	7.70	0.55	0.28	59.02	23.98	16.98
222-227	47.8	3.64		7.69	0.69	0.49			
227-232	47.8	2.73		7.53	0.65	0.42			
232-237	47.8	1.36		7.81	0.76	0.61			
237-242	47.8	0.0		7.59	0.83	0.51			
242-247	47.8	0.0	0.0	7.61	0.0	0.0	40.86	9.67	49.46
247-253	47.8	0.0		7.60	0.34	0.19			
253-258	47.8	0.0		7.51	0.18	0.12			
258-263	47.8	0.0		7.31	0.18	0.19			
263-268	47.8	0.0	0.0	7.38	0.66	0.13	51.96	14.32	33.70
268-273	47.8	0.0		7.40	0.97	0.05			
273-278	47.8	0.0		7.28	1.30	0.02			

SITE 5 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
278-285	47.8	0.0	0.0	7.21	0.0	0.0	89.70	5.88	4.41
285-288	47.8	0.0	0.0	7.24	0.19	0.05	84.83	0.0	15.16
288-292	47.8		0.0				93.31	0.0	6.68

SITE 6

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 6	68.4	0.0	2.34	6.33	0.84	0.41	62.79	2.32	34.88
6- 10	68.4	0.0	1.37	6.11	0.83	0.40	48.33	2.58	49.07
10- 14	68.4	0.0	1.58	5.92	0.88	0.44	37.33	6.33	56.33
14- 19	68.4	0.0	0.62	5.90	0.91	0.44	37.81	3.98	58.20
19- 24	68.4	0.0	0.24	6.03	0.89	0.43	35.67	2.52	61.79
24- 28	68.4	0.0	0.18	5.90	0.86	0.42	36.06	7.37	56.55
28- 32	68.4	0.0	0.06	6.12	0.92	0.45	45.16	18.95	76.20
32- 37	68.4	0.0	0.0	6.25	0.91	0.50	28.47	25.24	46.27
37- 42	68.4	0.0	0.04	6.28	0.93	0.57	30.82	24.35	44.81
42- 48	68.4	0.0	0.02	6.21	0.97	0.53	24.67	21.59	53.72
48- 54	68.4	0.0	0.09	6.40	0.96	0.57	35.25	18.70	46.04
54- 59	68.4	0.0	0.08	6.36	0.98	0.45	24.09	16.32	59.58
59- 64	68.4	0.0	0.0	6.41	0.90	0.49	24.72	17.09	58.18
64- 69	68.4	0.0		6.58	0.91	0.49			
69- 74	68.4	0.0	0.0	6.54	0.94	0.36	20.19	17.90	61.91
74- 79	68.4	0.0		6.60	0.88	0.42			
79- 84	68.4	0.0	0.0	6.65	0.89	0.51	16.57	16.00	67.42
84- 89	68.4	0.0		6.82	0.90	0.71			
89- 94	68.4	0.0		6.86	0.99	0.58			
94- 99	68.4	0.0	0.0	6.80	0.97	0.46	17.01	16.67	66.32
99-104	68.4	0.45		7.21	0.88	0.40			
104-109	68.4	3.64		7.40	0.85	0.35			
109-114	68.4	2.73	0.39	7.57	0.87	0.34	19.23	12.30	68.47
114-119	68.4	3.18		7.31	0.85	0.24			
119-124	68.4	5.91		7.54	0.84	0.42			
124-129	68.4	4.55	0.0	7.59	0.89	0.61	20.78	9.33	69.87
129-136	68.4	4.09		7.58	0.74	0.45			
136-140	68.4	5.46		7.65	0.85	0.63			

SITE 6 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
140-145	68.4	5.46	0.0	7.60	0.84	0.42	41.74	6.60	51.65
145-150	68.4	6.82		7.73	0.38	0.21			
150-155	68.4	5.91		7.70	0.53	0.43			
155-160	68.4	4.55	0.51	7.78	0.57	0.36	72.53	4.40	23.05
160-165	68.4	4.09		7.68	0.46	0.46			
165-170	68.4	0.91		7.61	0.42	0.19			
170-175	68.4	1.36	0.15	7.61	0.58	0.37	70.36	1.92	27.69
175-180	68.4	0.0		7.60	0.80	0.71			
180-185	68.4	0.0		7.45	0.84	0.39			
185-192	68.4	0.0	0.0	7.40	1.66	0.28	38.22	1.15	60.61
192-195	68.4	0.0	0.11	7.48	0.34	0.03	93.15	0.0	6.84
195-197	68.4	0.0	0.10	7.40	0.44	0.02	90.94	0.0	9.05

SITE 7

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 6	84.4	0.0	2.70	6.29	0.79	0.48	47.52	0.0	52.47
6- 11	84.4	0.0	2.56	6.00	0.80	0.43	47.35	1.98	50.66
11- 16	84.4	0.0	2.71	6.08	0.81	0.41	34.44	1.11	64.44
15- 19	84.4	0.0	2.25	5.95	0.90	0.43	32.46	2.31	65.21
19- 22	84.4	0.0	1.42	5.95	0.96	0.42	30.25	2.01	67.72
22- 25	84.4	0.0	1.61	6.00	0.98	0.43	43.18	1.51	55.30
25- 29	84.4	0.0	0.79	5.96	1.07	0.42	26.38	3.12	70.48
29- 33	84.4	0.0	0.92	5.97	1.04	0.39	33.41	6.49	60.09
33- 38	84.4	0.0	0.39	5.98	1.00	0.30	37.24	9.94	52.80
38- 46	84.4	0.0	0.14	6.14	1.07	0.40	31.86	11.02	57.10
46- 51	84.4	0.0	0.08	6.05	1.04	0.35	38.86	10.56	50.56
51- 55	84.4	0.0	0.04	6.10	1.16	0.56	26.15	9.80	61.30
55- 60	84.4	0.0	0.03	6.31	0.95	0.53	23.50	14.73	61.75
60- 65	84.4	0.0	0.01	6.40	0.95	0.36	29.04	20.23	50.11
65- 70	84.4	0.0	0.0	6.50	0.84	0.23	48.42	20.82	30.75
70- 75	84.4	0.0		6.45	0.88	0.41			
75- 80	84.4	0.0	0.0	6.63	0.87	0.43	16.81	23.99	41.25
80- 85	84.4	0.0		6.80	0.97	0.66			
85- 90	84.4	0.0	0.0	6.88	0.94	0.53	15.69	24.92	59.38
90- 95	84.4	0.0		7.15	0.90	0.48			
95-100	84.4	0.91		7.45	0.83	0.34			
100-105	84.4	0.45	0.40	7.67	0.90	0.44	27.27	9.38	63.34
105-109	84.4	2.73		7.42	0.85	0.31			
109-114	84.4	5.00		7.54	0.83	0.55			
114-120	84.4	6.37	0.0	7.70	0.79	0.41	13.47	2.12	84.39
120-126	84.4	4.55		7.65	0.79	0.44			
126-132	84.4	5.00		7.80	0.79	0.53			
132-137	84.4	3.64	0.0	7.80	0.74	0.34	64.98	6.72	28.29

SITE 7 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
137-142	84.4	3.18		7.75	0.87	0.49			
142-147	84.4	3.18		7.81	0.75	0.16			
147-152	84.4	0.91	0.12	7.82	0.86	0.35	50.79	5.75	43.45
152-157	84.4	0.0	0.0	7.61	0.66	0.38	46.68	5.36	47.94
157-161	84.4	0.0	0.0	7.58	0.53	0.33	43.97	9.44	46.57
161-164	84.4	0.0	0.07	7.54	0.16	0.0	89.34	0.0	10.65

SITE 8

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 8	95.5	0.0	1.77	6.85	0.88	0.48	30.74	0.21	69.05
8- 13	95.5	0.0	1.70	6.38	0.90	0.47	41.32	0.0	58.68
13- 18	95.5	0.0	1.38	5.70	1.01	0.45	29.28	0.60	70.12
18- 25	95.5	0.0	0.94	5.55	1.03	0.44	26.87	3.56	69.57
25- 30	95.5	0.0		5.58	1.08	0.32			
30- 34	95.5	0.0	0.20	5.48	1.05	0.25	22.06	4.92	73.02
34- 39	95.5	0.0		5.50	1.20	0.28			
39- 44	95.5	0.0	0.06	5.51	1.02	0.35	25.25	8.69	66.06
44- 49	95.5	0.0		5.73	1.26	0.67			
49- 54	95.5	0.0	0.0	5.74	1.16	0.47	17.04	4.42	78.54
54- 59	95.5	0.0		5.87	1.01	0.38			
59- 64	95.5	0.0	0.0	6.09	0.98	0.19	37.24	20.04	42.72
64- 69	95.5	0.0		6.50	0.65	0.11			
69- 74	95.5	0.0	0.0	6.40	0.92	0.22	29.00	21.67	49.33
74- 79	95.5	0.0		6.57	0.93	0.29			
79- 83	95.5	0.0	0.0	6.60	1.42	0.29	21.04	24.17	54.79
83- 88	95.5	0.0		6.48	1.33	0.67			
88- 93	95.5	0.0	0.0	6.43	1.38	0.52	10.41	23.12	66.47
93- 98	95.5	0.0		6.52	0.96	0.34			
98-103	95.5	0.0	0.0	6.59	1.50	0.23	28.20	21.50	50.30
103-108	95.5	0.0	0.0	6.61	1.00	0.37	20.82	20.42	58.76
108-113	95.5	0.0	0.0	6.60	0.71	0.29	25.10	16.86	58.04
113-118	95.5	0.0	0.0	6.74	1.05	0.35	33.89	10.81	55.30
118-125	95.5	0.0	0.0	6.72	0.79	0.37	30.75	24.37	44.87
125-130	95.5	0.0	0.0	6.72	1.30	0.49	19.29	16.90	63.81
130-133	95.5	0.0	0.0	6.50	0.82	0.29	29.46	18.81	51.73
133-138	95.5	0.0	0.0	6.79	0.70	0.34	36.43	15.00	48.57
138-144	95.5	0.0		6.73	0.56	0.29			

SITE 8 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
144-150	95.5	0.0	0.0	6.72	1.08	0.24	27.27	3.41	69.32
150-156	95.5	0.0	0.0	7.03	0.33	0.02	90.50	0.0	9.50
156-168	95.5		0.0				81.92	0.0	18.08
168-174	95.5		0.0				82.13	0.0	17.87

SITE 9

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 6	116.2	0.0	2.40	6.23	0.65	0.44	39.60	1.40	58.98
6- 9	116.2	0.0	1.66	6.20	0.62	0.45	27.07	3.97	68.95
9- 12	116.2	0.0	1.22	5.95	0.72	0.44	28.74	0.89	70.35
12- 17	116.2	0.0	1.08	5.75	0.74	0.39	18.81	2.58	78.59
17- 22	116.2	0.0	1.13	5.74	0.87	0.41	19.37	3.13	77.49
22- 25	116.2	0.0	0.40	5.76	0.94	0.46	19.89	3.18	76.92
25- 28	116.2	0.0	0.12	5.81	0.98	0.56	17.73	4.06	78.19
28- 32	116.2	0.0	0.04	5.83	1.00	0.78	12.50	3.97	83.52
32- 36	116.2	0.0	0.05	5.89	1.18	0.66	13.24	4.67	82.07
36- 41	116.2	0.0	0.11	6.05	1.01	0.80	27.83	10.05	62.11
41- 46	116.2	0.0	0.14	6.07	1.44	1.11	11.14	3.01	85.84
46- 52	116.2	0.0	0.0	6.23	1.11	0.36	13.30	4.43	82.26
52- 56	116.2	0.0	0.0	6.45	1.38	0.96	14.11	6.04	79.83
56- 58	116.2	0.0	0.0	6.45	0.0	0.22	10.18	1.45	88.36
58- 63	116.2	0.0	0.0	6.58	0.64	0.26	30.85	18.28	50.85
63- 68	116.2	0.0		6.77	0.60	0.15			
68- 73	116.2	0.0		7.10	1.03	0.34			
73- 78	116.2	0.0	0.0	7.25	0.70	0.42	42.41	8.96	48.62
78- 83	116.2	0.0		7.52	0.62	0.25			
83- 88	116.2	0.0		7.80	0.47	0.31			
88- 94	116.2	0.0	0.0	7.54	0.71	0.65	15.22	3.80	80.96
94- 99	116.2	0.0		7.75	1.16	0.27			
99-104	116.2	0.0		7.74	1.12	0.34			
104-109	116.2	0.0	0.0	7.56	1.05	0.32	62.27	1.81	35.90
109-114	116.2	0.0		7.42	0.90	0.21			
114-120	116.2	0.0		7.30	0.51	0.11			
120-126	116.2	0.0		7.26	0.51	0.10			
126-131	116.2	0.0	0.0	6.92	0.61	0.06	37.78	0.46	61.75

SITE 9 (CONTINUED)

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
131-136	116.2	0.0	0.0	7.20	0.22	0.0	95.90	0.0	4.09
136-140	116.2	0.0		7.05	0.37	0.0			

SITE 10

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 8	136.7	0.0	2.09	6.90	0.47	0.23	27.04	0.0	72.96
8- 13	136.7	0.0	1.35	5.98	0.49	0.19	22.79	0.0	77.23
13- 18	136.7	0.0	0.97	5.75	0.62	0.15	37.07	0.57	62.36
18- 22	136.7	0.0	0.60	5.86	0.88	0.46	20.68	0.0	78.32
22- 26	136.7	0.0	0.28	5.92	1.18	1.56	12.62	0.90	86.48
26- 31	136.7	0.0	0.07	6.11	0.97	0.85	24.26	0.0	75.83
31- 36	136.7	0.0	0.04	6.10	1.14	0.75	28.33	0.69	70.98
36- 42	136.7	0.0	0.04	6.28	1.00	1.06	21.88	0.45	78.12
42- 47	136.7	0.0	0.02	6.28	1.06	0.89	20.27	2.13	77.60
47- 52	136.7	0.0	0.04	6.37	2.30	0.72	18.30	1.52	81.70
52- 57	136.7	0.0	0.0	6.31	0.63	0.33	17.93	3.79	78.28
57- 62	136.7	0.0	0.0	6.24	0.55	0.31	27.94	3.99	72.06
62- 66	136.7	0.0	0.0	6.35	1.50	0.60	12.04	5.02	82.94
66- 68	136.7	0.0	0.0	6.40	1.64	0.84	17.78	7.26	74.96
68- 73	136.7	0.0	0.0	6.36	0.22	0.21	31.22	3.88	64.90
73- 78	136.7	0.0	0.0	6.50	0.70	0.35	29.09	7.27	63.64
78- 83	136.7	0.0	0.0	6.45	0.88	0.44	26.15	5.96	67.89
83- 86	136.7	0.0	0.0	6.50	1.06	0.32	28.58	0.90	70.85
86- 96	136.7	0.0	0.0	6.32	0.38	0.34	25.93	4.44	69.53
96-100	136.7	0.0	0.0	6.40	0.88	0.04	44.46	2.25	53.29
100-103	136.7	0.0	0.0	6.50	0.30	0.0	76.36	0.0	23.64
103-108	136.7	0.0	0.05	6.33	1.07	0.0	54.80	0.0	45.20
108-113	136.7	0.0	0.09	6.26	0.77	0.0	88.98	0.0	11.02
113-116	136.7		0.0				90.46	0.0	9.54

SITE 11

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 6	148.5	0.0	1.88	6.08	0.45	0.27	38.86	0.0	61.14
6- 11	148.5	0.0	0.97	5.15	0.49	0.09	37.18	0.24	62.58
11- 17	148.5	0.0	0.60	5.25	0.54	0.09	38.37	0.0	61.63
17- 22	148.5	0.0	0.41	5.71	0.76	0.27	33.24	0.0	66.76
22- 27	148.5	0.0	0.19	5.96	0.71	0.31	32.95	1.52	65.53
27- 32	148.5	0.0	0.10	6.20	0.66	0.32	33.14	1.70	65.16
32- 37	148.5	0.0	0.0	6.20	0.49	0.75	19.74	3.73	77.53
37- 42	148.5	0.0	0.0	6.21	0.81	1.03	12.56	5.17	82.26
42- 48	148.5	0.0	0.0	6.18	0.52	0.14	19.61	9.48	70.91
48- 53	148.5	0.0	0.0	6.19	1.28	0.90	28.32	3.76	67.92
53- 58	148.5	0.0	0.0	6.20	0.67	0.18	46.79	0.0	53.21
58- 64	148.5	0.0	0.0	6.30	0.66	0.25	35.12	3.27	61.61
64- 68	148.5	0.0	0.0	6.12	0.84	0.06	21.09	4.76	74.15
68- 75	148.5	0.0	0.0	6.25	0.27	0.08	36.03	6.13	57.84
75- 80	148.5	0.0		6.20	0.29	0.18			
80- 85	148.5	0.0	0.0	6.28	0.88	0.10	12.18	3.68	84.14
85- 90	148.5	0.0		6.19	1.03	0.11			
90- 96	148.5	0.0	0.0	6.16	0.90	0.41	25.60	6.33	68.07
96-102	148.5	0.0	0.0	6.27	0.09	0.0	69.70	4.05	25.45
102-109	148.5		0.0				95.02	0.0	1.24
109-118	148.5		0.0				98.06	0.0	1.11

SITE 12

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 5	160.5	0.0	1.40	7.09	0.46	0.30	52.83	0.0	47.17
5- 7	160.5	0.0	1.59	6.99	0.53	0.38	47.97	0.0	52.03
7- 14	160.5	0.0	1.03	6.20	0.55	0.29	37.58	0.0	62.42
14- 19	160.5	0.0	0.70	5.81	0.71	0.34	16.77	0.0	83.22
19- 24	160.5	0.0	0.51	5.80	0.85	0.51	18.24	0.0	82.76
24- 29	160.5	0.0	0.40	5.73	0.88	0.32	16.67	0.0	83.33
29- 33	160.5	0.0	0.20	5.60	0.85	0.47	17.40	2.70	79.90
33- 38	160.5	0.0	0.11	5.90	0.87	0.33	24.62	4.61	70.77
38- 43	160.5	0.0	0.0	6.38	0.76	0.47	34.45	7.62	57.93
43- 47	160.5	0.0	0.0	6.39	0.70	0.12	15.04	1.75	83.21
47- 52	160.5	0.0	0.0	6.68	0.35	0.08	12.44	1.37	86.19
52- 55	160.5	0.0	0.0	6.77	1.02	0.14	27.00	6.93	66.07
55- 58	160.5	0.0	0.0	6.41	1.29	0.20	11.63	2.33	85.04
58- 62	160.5	0.0	0.0	6.39	1.04	0.46	16.23	3.49	80.23
62- 64	160.5	0.0	0.01	6.40	0.79	1.36	5.22	0.78	94.00
64- 69	160.5	0.0	0.0	6.60	0.39	0.0	30.80	3.80	65.40
69- 73	160.5	0.0	0.0	6.66	0.70	0.55	20.51	2.56	76.93
73- 78	160.5	0.0	0.0	6.69	1.18	0.40	29.01	2.47	68.52
78- 83	160.5	0.0	0.0	6.63	1.05	0.26	15.68	0.63	83.96
83- 88	160.5	0.0	0.0	6.50	0.96	0.06	70.00	0.0	30.00
88- 92	160.5	0.0	0.0	6.60	0.65	0.02	78.30	0.0	21.70
92- 96	160.5		0.0				75.00	0.0	25.00
96-101	160.5		0.0				82.16	0.0	17.84

SITE 13

DEPTH (IN.)	DIST. (MI.)	CARB. %	ORG. C %	PH	FE %	MN %	PRIM. %	MICA %	CONC. %
0- 8	173.2	0.0	1.39	5.35	0.60	0.33	22.89	0.0	77.09
8- 12	173.2	0.0	0.66	5.45	0.76	0.34	7.89	0.0	92.09
12- 16	173.2	0.0	0.49	5.31	1.16	1.05	4.14	0.0	95.85
16- 21	173.2	0.0	0.50	5.35	1.07	0.73	3.55	0.0	96.44
21- 26	173.2	0.0	0.28	5.50	0.90	0.49	6.56	0.0	93.43
26- 30	173.2	0.0	0.19	5.79	0.93	0.60	4.58	0.91	94.49
30- 35	173.2	0.0	0.07	5.95	0.97	0.66	5.90	1.24	92.85
35- 40	173.2	0.0	0.02	6.20	0.81	0.24	9.22	0.86	89.91
40- 44	173.2	0.0	0.0	6.42	1.04	0.56	10.11	0.89	88.98
44- 49	173.2	0.0	0.04	6.33	0.51	0.42	12.37	2.00	85.61
49- 54	173.2	0.0	0.0	6.34	1.06	0.43	6.61	0.73	92.64
54- 59	173.2	0.0	0.0	6.60	1.30	1.52	2.84	0.31	96.83
59- 65	173.2	0.0	0.0	6.59	1.29	0.94	4.78	0.84	94.36
65- 68	173.2	0.0	0.0	6.50	3.30	0.18	2.06	1.37	96.55
68- 75	173.2	0.0	0.0	6.55	0.65	0.16	63.88	0.0	36.11
75- 80	173.2	0.0	0.08	6.42	0.23	0.05	95.33	0.0	4.66
80- 85	173.2	0.0	0.0	6.58	0.54	0.02	91.86	0.0	8.13
85- 88	173.2	0.0	0.0	6.42	0.56	0.02	94.36	0.0	5.63
88- 91	173.2		0.0				92.73	0.0	7.26
91- 96	173.2		0.0				96.79	0.0	3.00